THE STUDY OF DIMENSIONAL AND GEOMETRICAL PROPERTIES OF WEFT KNITTED FABRICS CONSTRUCTED FROM COTTON YARNS

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بسم الله الرحمن الرحيم

IN THE NAME OF GOD

THE BENEFICIENT, THE MERCIFUL

ABSTRACT

THE STUDY OF DIMENSIONAL AND GEOMETRICAL PROPERTIES OF WEFT KNITTED FABRICS CONSTRUCTED FROM COTTON YARNS

Ali-Asghar Asgharian-Jeddi

The present thesis is an account of an investigation into the dimensional parameters of plain, rib and interlock knitted fabrics produced from different cotton yarn constructions, and their relationship with stitch length and the effect of mechanical and chemical relaxation treatments on the dimensions of these fabrics. The dimensions are described in terms of the "K_s" and "K_r" values of the fabrics.

The "K_s" values for cotton fabrics obtained after a complete relaxation are given below, alongside those previously obtained for wool fabrics:

Structure	Cotton	Wool
Plain	25.1	23.6
Rib	18.5	16.9
Interlock	28.2	25.2

It was noted that the cotton values are higher than wool fabrics at a similar stage of relaxation. This fact was attributed to the difference of fibre density of cotton and wool, and it was confirmed theoretically, that differences of this order for cotton and wool would be expected when allowing for differences in fibre density of the two materials.

Investigation of the effect of mercerizing treatment on the cotton fabrics suggested that after this treatment the structures were brought most nearly to a relaxed state.

The fraction of the air space in the fabrics, was calculated from (1 – C.F.)%, and these calculated results were compared with the measured air permeability of the fabrics. The results were in a good agreement with the theoretical relationship between the air permeability and the air space in the fabric not covered by yarn.

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LIST OF SYMBOLS

(D.R.)	Dry relaxation
(W.R.)	Wet relaxation
(W.R.+T.D.)	Wet relaxation and tumble dry
G(W.M.+T.D.)	Washing and tumble drying treatment on the fabrics which were previously relaxed under (D.R.), (W.R.) and (W.R.+T.D.)
G(C.S.+T.D.)	Caustic soda treatment on the fabrics which were previously relaxed under (D.R.), (W.R.), (W.R.+T.D.) and G(W.M.+T.D.)
G(M.+T.D.)	Mercerizing treatment on the fabrics which were previously relaxed under (D.R.), (W.R.), (W.M.+T.D.), G(W.M.+T.D.) and G(C.S.+T.D.)
(W.M.+T.D.)	Washing and tumble drying on the fabrics immediately after (D.R.)
(C.S.+T.D.)	Caustic soda treatment on the fabrics immediately after (D.R.)
(M.+T.D.)	Mercerizing treatment on the fabrics immediately after (D.R.)
(C.P.cm.)	Courses per unit length
(W.P.cm.)	Wales per unit length
(S)	Stitch density per unit area
(ℓ)	Stitch length
(A.S.%)	Area shrinkage percentage
(C.F.)	Cover factor
(A.P.)	Air permeability
(1 – C.F.)%	Air space percentage

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CHAPTER I

GENERAL ASPECTS OF DIMENSIONAL PROPERTIES OF KNITTED FABRICS

I.1 Introduction

In recent years, a considerable expansion in the production rate of the knitting section of the textile industry has made the use of knitted fabric very popular in certain market areas. The increasing demand for knitted fabric is partly due to the development of new fibres, but mainly due to the technological improvements in knitting machinery, which are now able to produce many new structures and provide much greater scope in patterned fabrics.

Weft knitted fabric, which is one of the two distinct classes of knitted fabrics(the other type of knitted fabrics is named warp knitted fabric), because of its cost of production, plus easy fit properties, is an ideal type of fabric in the underwear market and also in the legwear area. In addition, for casual outerwear, the weft knit is used extensively in the traditional market of cardigans and pullovers.

Knitted garments have long been notorious for their undesirable tendency to shrink on wearing and washing. Shrinkage is the difference in fabric dimensions before and after a relaxation treatment such as laundering.

The dimensional properties of all knitted fabrics will be changed after leaving the knitting machine , because these fabrics are produced from a series of intermeshing loops, and these loops are readily distorted in the manufacturing processes of knitting, finishing, and garment fabrication.

For cotton knitted fabrics, which is the object of the work described in this thesis, the shrinkage from washing has always been considered a serious problem. It has become even more critical in recent years with the demand for such cotton products as knitted dress shirts, sports slacks, blouses, and dresses. And the use of tumble drying to dry garments after washing has also not helped!

To produce a satisfactory fabric, the finished dimensions must be know, the physical properties must be predictable, the cost must be reasonable and it must be easy to produce. Textile machinery manufacturers have realized the necessity of improved finishing procedures to meet new shrinkage control requirements.They operate by relieving the fabric distortions that have occurred during knitting and in some of the subsequent finishing steps. By using these processes in conjunction with chemical crosslinking treatments, satisfactory shrinkage control for cotton knitted fabrics can be expected.

Shrinkage of a knitted fabric is determined by many factors which affect the change in fabric dimensions such as fiber characteristics, stitch length, machine gauge, yarn twist, yarn count, knitting tension, type of machine, type of needle, type of fabric, the method of relaxation procedure, the method of washing, finishing, drying, etc. It is evident that some of the above factors have a major influence on fabric shrinkage and others have a very marginal effect. However, the factors mostly responsible for shrinkage are known to be the swelling of yarn[1] and the relaxation of internal stress imposed on the yarn during the knitting process.

Problems of shrinkage and instability are associated with distortions away from the stable state of the fabric. Ideally, all fabrics should be produced with their dimensions as near as possible to those of the stable state.

On removal of the distortion force, the fabric will attempt to return to its relaxed minimum energy state though it may not achieve this because of the frictional restraints. These frictional forces can be minimized by application of lubricants and they may be overcome by supplying additional energy to the fabric. In theory, this stable or fully-relaxed state is a minimun energy state but, in practice many different relaxation techniques such as soaking, agitation, vibration have been examined singly and in combination and there is now general agreement that a combination of mild washing and tumble drying provides the most effective and reproducible method of relaxation.

The fundamentals of fabric distortion are based on the fabric loops distortion during the manufacturing processes of knitting, finishing, and garment fabrication. This temporary distorted state of knitted fabric is relieved in subsequent laundering and a change in the dimensions of the garment is observed. These dimensional changes usually occur as length and width shrinkage, although in some cases the length shrinkage results in a corresponding growth in width. Figure(1.1) illustrates the loop construction of plain jersey fabric as follows:

a) high distortion in the length.

b) high distortion in the width.

c) low distortion in length and width.

The prior attempts to rationalise the properties of knitted fabric commenced in the early part of the twentieth century[2]. More recently, several studies of loop shape and the geometry of the knitted fabric and the effect of various relaxation treatments on the fabric dimensional properties have been made which will be explained in more detail in chapters II and III.

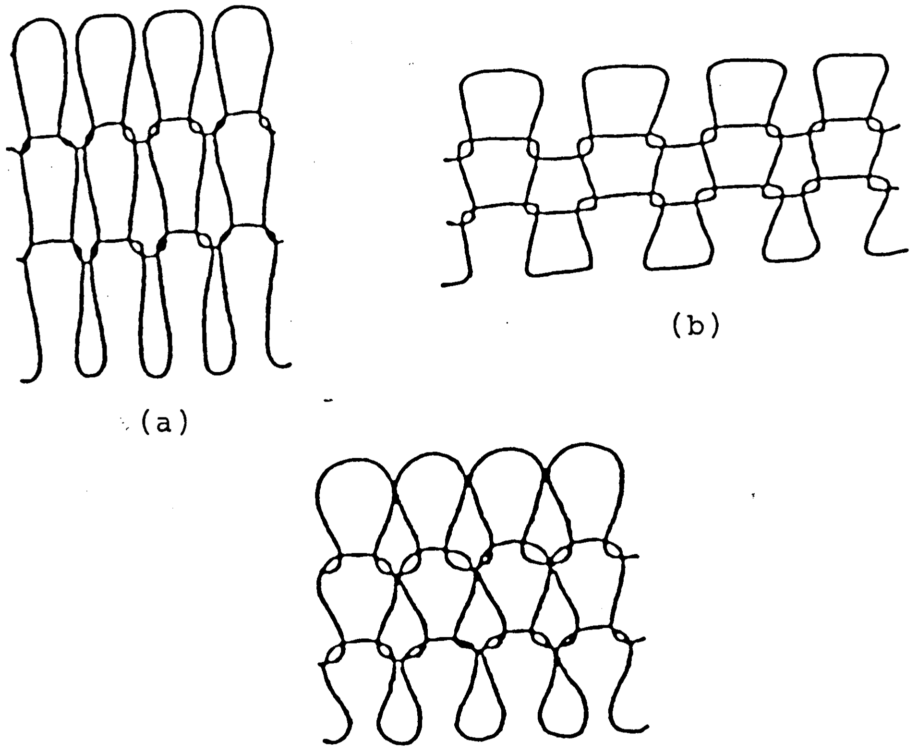
The problem of shrinkage in knitted fabrics, has been studied by Leigh[3], who, for convenience, divided the yarn into three groups:

a) hydrophilic yarns.

b) wool

c) hydrophobic yarns.

He emphasized that, in general, fabrics knitted from hydrophilic yarn, (eg. cotton, silk and rayon), exhibit their greatest area shrinkage when first wetted out. During



(a) (b) (c)

Figure(1.1) Loop construction of plain jersey fabric;

(a) high distortion in the length,

(b) high distortion in the width,

(c) low distortion in length and width.

subsequent washing only small changes in area shrinkage occur. In contrast, wool knitted fabric has a different behaviour. On first wetting out there is an area change of the same order of magnitude as for hydrophilic yarns, but further washing produces continued shrinkage, and as the fabric decreases in area it becomes thicker and stiffer. The fibres become more matted and the fabric loses much of its extensibility. This is known as felting.

Fabrics knitted from hydrophobic yarns, such as polyamide (eg. nylon) and polyester (eg. Terylene) staple fibre yarns, also exhibit their greatest area shrinkage when first wetted out. However, the shrinkage is less than for hydrophilic and wool yarns. Only slight changes in area occur during subsequent washing.

I.2 Relaxation Treatments Causing Dimensional Changes:

Several authors have used the term relaxation shrinkage to explain the release of mechanical strains during wetting out and washing. Munden[4] divided fabric shrinkage into three categories as follows:

a) Relaxation Shrinkage:

This is the shrinkage observed when fabrics, made from any fibre, are first wetted out statically in water. The shrinkage obtained has been considered to be a measure of the strains imparted to the fabric during finishing. The largest decrease in area occurs when first wetted out, but the extent of the shrinkage decreases each time.

b) Consolidation Shrinkage:

This is the further shrinkage which takes place normally after relaxation shrinkage. It is used to describe the further shrinkage of cotton and man-made fibre fabrics during washing and after a standard wet relaxation treatment.

C) Felting Shrinkage:

This shrinkage is only observed in fabrics composed partly or completely of wool and animal hairs. This type of shrinkage is the progressive shrinkage during washing of wool fabrics, caused by the interlocking of the scale-like structure.

I.3 Chemical Relaxation Treatment On Cotton Knitted Fabric:

I.3.1 Introduction

By either mechanical relaxation treatments,i.e.,consecutive laundering and tumble-drying cycles, or chemical treatments such as mercerization without tension, it is possible to obtain dimensional stability in cotton knitted fabrics.

Mechanical methods are based on the concept that relaxation is a mechanical phenomenon. It should be noticed that some of the mechanical properties of a fabric must arise from the molecular interactions within its constituent fibres. Munden(4) indicated, the relatively large dimensional changes that occur on wetting and drying a fabric composed of hydrophilic fibres illustrate the importance of molecular mobility in determining the stable state. If a chemical process that would bring about complete relaxation could be developed, it would be of commercial interest; it would certainly be simpler, faster, and cheaper than the mechanical method. On the basis of this hypothesis that relaxation shrinkage of knitted fabrics arises in the main from molecular interactions within the fibres a mercerization (without tension) technique has been developed for plain jersey cotton structures, which achieves fabric stabilization much faster than by mechanical relaxation methods[5].

I.3.2 Mercerizing

John Mercer observed in 1844 that when cotton was treated with concentrated sodium hydroxide (caustic soda solution) there was a swelling of the cross-section of the fibres which was accompanied by a shrinkage in length. The yarns also benefited by increased powers of receiving colours in printing and dyeing, and greater strength and finenss.

The advantage of treating yarns and fabrics in these solutions was not appreciated until 1889-90, when Harace-Lowe found that by treating the fabric under tension a highly attractive lustre could be imparted to the material. In practice most mercerising treatments are given to increase the lustre of the yarn, which requires that the cotton fabric must be maintained at its original length.

This can be achieved in one of the two following ways:

a) the fabric must be held in length throughout the whole process of treatment with caustic soda and then also during washing;

b) the fabric is impregnated with caustic soda in a relaxed state, which helps the penetration of the chemical. Then it is brought to the original dimensions before washing. This method is more commonly used.

It has been found that[6] mercerization gives single knits, interlocks and warp knit fabrics from 100% cotton the following quality improvements:

a) lustre (develops only when tension is applied to the fabric or yarn while it is swollen with sodium hydroxide, and that tension must be maintained during washing-off);

b) dimensional stability with residual shrinkage in length and width under 4% at a predetermined and reproducible finished width;

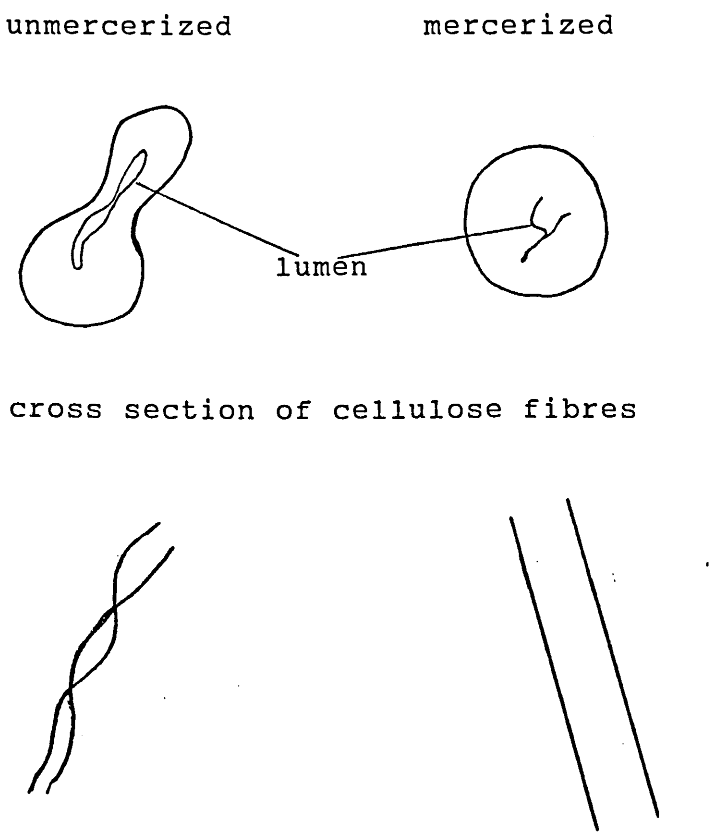
c) a more level appearance after dyeing with improved cover of immature fibre on dark shades;

d) improved strength, particularly when resin finishing is required.

I.3.3 The Effect Of Mercerizing On Cotton Fibres

During mercerization treatment, the cotton fibres swell, untwist rapidly and become translucent. If it is washed at this stage, the alkali cellulose is decomposed as follows:

But the fibre remains in the swollen condition and the convolutions of the fibre will disappear. The fibre appears a smooth rod, with a round cross-section and a cracked lumen. Figure(1.2) shows the cross section and longitudinal view of cotton fibres under the microscope.



Figure(1.2)

CHAPTER II

PREVIOUS WORK ON THE GEOMETRICAL ANALYSIS AND DIMENSIONAL PROPERTIES OF WEFT-KNITTED STRUCTURES

II.1. Previous Work On Plain-Knitted Structure

II.1.1 Early Experimental Work

The study of fabric geometry and dimensional stability of knitted fabrics has been one of the most discussed subjects in the textile industry as well as in research fields. This subject has spanned at least 70 years, with Tompkins[2] generally being credited with the first publications in this area, and he made the earliest recorded attempt to rationalize the properties of knitted fabrics.

The first extensive study on the dimensional behaviour and stabilization of the plain jersey structure was done by Dutton[7] who considered the effect of yarn and machine variables on the uniformity and dimensional stability of knitted fabric. He found in his investigation on plain wool knitted fabric that, the actual structure of the fabric can affect the shrinkage and wearing property, as well as the ability of a garment to retain its shape during wear and washing. He showed in his consideration that, the knitting and finishing processes are interdependent, and that it was most desirable that there should be co-operation between the knitters and finishers in order to obtain the best results.

Doyle[8] is the first person who suggested that the length of yarn per stitch be regarded as a factor of fundamental importance for the measurement of knitting quality since it is independent of the fibres from which the yarn is spun. This suggestion was found following experimental studies of a wide range of relaxed plain knit fabrics. He expressed the total number of stitches per unit area in terms of commonly measured factors, i.e., the number of courses and wales per unit length as follows:

$$S=C \cdot W$$

where S=stitch density

C=number of courses per unit length

W=number of wales per unit length

Doyle found a unique relationship existed between stitch density and length of yarn knitted into the stitch which he showed was independent of the fibre type. He found that fabrics after standing attained area dimensions given by:

$$S= \frac{19.3}{\ell^2}$$

where ℓ=the length of yarn knitted into the stitch

In 1958 , Leaf[9] showed that, when a homogeneous elastic rod is bent into a loop in one plane by bringing its two ends together and parallel, providing the rod is not plastically deformed by the bending, it takes up a definite configuration, which is independent of the physical properties, the length of the loop or thickness of the material forming the loop.

Munden[10] suggested that this physical property, was probably responsible for the similar shape of knitted loops when relaxed from strain, and extended Doyle's[8] work to investigate the length, width, and ratio of length to width of loops in fabrics released from strains. In the process he identified two equilibrium states:

i) Dry Relaxation:

In the dry state, the fabrics may be expected to return to their strain free condition if left on a flat surface for 24 hours.

ii) Wet Relaxation:

It is generally appreciated that fabrics knitted from hydrophilic yarns may be brought to a strain free condition by soaking in water with a wetting and agent followed by the fabrics being allowed to dry on flat smooth surface.

He suggested that, the dimensions in the completely stable configuration corresponded to minimum energy. Thus, this configuration is a geometrical property of the loop structure and is independant of the properties of the material composing the loop. In conformation with these ideas, he found experimentally for wool fabrics in both the dry and wet relaxed state, linear relationships between the course and wale spacing and length of the loop of the plain knit fabric. These relationships were described in the following form:

$$K_s = S.\ell^2 \qquad (1)$$

$$K_c = (c.p.i).\ell \qquad (2)$$

$$K_w = (w.p.i).\ell \qquad (3)$$

$$K_r = \frac{K_c}{K_w} = \frac{c.p.i}{w.p.i} \qquad (4)$$

where "S" is stitch density and "K_s", "K_c", "K_w" and "K_r" are constants called fabric dimensional parameters. c.p.i and w.p.i are the number of courses and wales per inch respectively.

The "K" values obtained empirically from a range of plain knit wool fabrics produced from a variety of counts and machines, are given below in Table(2.1).

	Dry Relaxed	Wet Relaxed
K_s	19.2	21.6
K_c	5.0	5.3
K_w	3.8	4.1
K_r	1.3	1.3

Table(2.1) "K" values for plain knit wool fabrics.

Munden also suggested that fabrics knitted from other type of yarns available at the time also gave similar relationships as far as area measurements are concerned. These results, he summarized as given in Table(2.2). He gave the results for linear measurements on fabrics knitted from these other yarns.

The $K_r = \frac{c.p.cm}{w.p.cm}$ parameter is a measure of the ratio of width of the loop to the length of the loop, and it, thus, may be defined as the loop shape factor. Munden's[10] loop model indicates that this ratio for knitted fabrics in the relaxed state of loop configuration, must be a constant which he found experimentally to be 1.3. Any fabric distortion, however has a marked effect on this ratio because of an increase in the one dimension which is imposed by such distortion will be accompanied by a decrease in the other. He suggested that as fabrics relax the "K_r" value becomes more constant, and that, the uniformity of the value of "K_r" is an indication of the effectiveness of the relaxation treatment.

Yarn	Dry Relaxed	Wet Relaxed
Wool	19.0 ± 0.3	21.6 ± 0.1
Cotton	19.0 ± 0.8	22.6 ± 0.5
Regular orlon	18.5 ± 1.0	18.5 ± 1.0
Staple nylon	18.5 ± 1.0	18.5 ± 1.0

Table(2.2) Values of "K_s" after Dry and Wet Relaxation for plain knit fabrics knitted from different yarn materials

Some important fabric parameters may be derived from the (1.4) equations, in terms of stitch length as follow:

weight gram/m^2 = $S.\ell.g$

$$= \frac{K_s}{\ell^2} .\ell.g(100)^2 = \frac{(100)^2 K_s.g}{\ell} \qquad (5)$$

$$\text{fabric width} = \frac{N}{\text{w.p.cm}} = \frac{N.\ell}{K_w} \qquad (6)$$

$$\text{weight per running metre} = \frac{\text{weight}(\text{gram/m}^2)\cdot\text{fabric width}}{100}$$

$$= (100\ K_c \cdot g)N \qquad (7)$$

where ℓ= stitch length (cm)

S= stitch density/cm^2

g= yarn weight (gram/cm)

N= number of needles

II.1.2 Geometrical Analysis

Once it became clear that the dimensions of a fabric were predictable from experimental formulae, it became evident that in order to explain dimensional changes it was desireable to establish a realistic loop model for the knitted structure.

Chamberlain[11] was the first to propose a simple mathematical model of the plain stitch structure which consisted of circular arcs and straight line arms to represent the knitted loop. From these configurations he established the following mathematical relationships:

$$\text{Ratio between } \frac{\text{number of courses}}{\text{number of wales}} = \frac{2}{\sqrt{3}} \qquad (8)$$

$$\text{the effective covering diameter of the yarn} = \frac{W}{4} \qquad (9)$$

$$\text{stitch length} = \frac{W(3\pi + 2\sqrt{13})}{4} \qquad (10)$$

where W= the width of wale

From these relationships, Finlayson[8] derived the following:

Stitch Density (S) = (number of courses).(number of wales)

$$S = \frac{2}{\sqrt{3}} \text{ (number of wales)}^2 = \frac{2}{\sqrt{3}\, W^2}$$

$$S = \frac{2}{\sqrt{3}} \cdot \frac{(3\pi + 2\sqrt{13})^2}{16(\ell)^2}$$

$$S = \frac{20}{\ell^2} \tag{11}$$

Chamberlain's model was further developed by Peirce[12], who used the diameter of the yarn and the wale and course spacings, to derive appropriate equations as follows:

$$\ell = 2p + w + 6\sqrt{\frac{4}{\pi}} \cdot \sqrt{\frac{g}{\rho}}$$

where ℓ= length of yarn in a unit cell or in one stitch

ρ= yarn density

which can also be expressed as:

$$\ell = 2p + w + 5.94d \tag{12}$$

$$\text{weight per unit area of cloth} = W = \frac{\ell \cdot g}{w \cdot p} \tag{13}$$

where p= course spacing

w= wale spacing or width per wale

g= weight per unit length of yarn

d= yarn diameter

Peirce stated in the rib knit, that there are twice as many loops per unit cell, enclosed within one course length and the repeat of the structure, as seen from one side. Thus, the same relationships for flat plain knitting may be applied to the rib knit if "ℓ" is the length of one loop and not the length in a unit cell, and "w" is the reciprocal of the total number of wales per unit length on both sides of the cloth.

Experimental data from knitted fabrics was not used by Peirce to verify these theoretical relationships, but Fletcher and Roberts[13] attempting to remedy this matter, reported a laboratory investigation in which they subjected a wide range of knitted plain fabrics to washing treatments and then used the experimental values of courses per inch, wales per inch and stitch length measurements to compare with results theoretically predicted from the Peirce equation. For the cellulosic fabrics, using a value for the specific density of cotton yarn of 1.1, they found that these results fitted an equation similar to that proposed by Peirce, vis., $\ell = 2p + w + 4.56\,d$.
They also indicated that the weight of the fabrics calculated by the Peirce's formula (13) showed good agreement with that obtained by weighing a known area of the washed sample.

Leaf and Glaskin[14] showed that the Peirce and Chamberlain models were not physically realistic in that they suggested discontinuities in the torsion along the loop. The torsion and curvature of the loop would therefore change and the shape of the loop would also change.

They proposed a further model which overcame these difficulties, in which they assumed that the projection of the central axis of the yarn on the plane of the fabric is composed of circular arcs, and found an approximation for the length of yarn in the loop as follows:

$$\ell = 4a \cdot \varphi \cdot d \tag{14}$$

where $$\varphi = \pi + \sin^{-1}\left\{ \frac{c^2 \cdot d}{[c^2 + w^2(1-c^2 \cdot d^2)^2]^{\frac{1}{2}}} \right\} - \tan^{-1} \frac{c}{w(1-c^2 \cdot d^2)}$$

$a = 1/(4w \cdot d \cdot \sin\varphi)$

d = yarn diameter

c = number of courses per inch

w = number of wales per inch

In 1960 Leaf[15] presented two different models of the plain-knitted loop. The first model described is the simpler of the two, but it can be applied only to wet relaxed fabrics. He formed first a two dimensional model of identical elasticas joined together to represent a loop. The third dimension was obtained, as Peirce had practised. He searched for another model which could be fitted to both wet relaxed and dry relaxed fabrics. The second model was more mathematically complex, but it provided a model which was a more complete picture of the plain knitted loop. However, the first model, because of its relative simplicity, may be useful in theoretical investigation only in wet relaxed fabrics. These models, although, of theoretical interest; suggested dimensional properties quite different from those found experimentally by Munden and other experimental investigations.

Later, Nutting and Leaf[16] attempted a different approach, to produce a general geometrical system which could be applied to all types of weft knitted structures. Thus, they suggested that the following simple equation can be used to describe the geometry of a fairly wide range of fabrics such as plain, 1X1 rib, interlock and double pique:

$1/c = A \cdot \ell$

where "A" is a constant, and "c" is course spacing.

They also, using the analysis of Love[17], indicated that the shape of a knitted loop, and hence the values of the fabric geometry constants, should depend on the ratio of flexural rigidity to torsional rigidity (B/G).

In 1967, Postle and Munden[18] proposed that the dry relaxed knitted loop configuration was determined by a fundamental consideration of the forces and couples acting on the loop at the interlocking points in the fabric. Initially, the loop was considered as a two dimensional structure and that the yarn behaved as a uniform homogeneous elastic rod that is straight in its stress-free configuration.

They found the following relationships for the knitted loop length "ℓ" and the relaxed fabric parameters by a mathematical analysis method:

$$\ell = \frac{P}{(\sin\alpha + \sin\beta)}\left[\left(\frac{\pi}{2} - \beta\right) + \sqrt{2(\sin\alpha + \sin\beta)\cdot f(\epsilon, \varphi_\beta)}\right] \qquad (15)$$

$$K_c = \frac{1}{(\sin\alpha + \sin\beta)}\left[\left(\frac{\pi}{2} - \beta\right) + \sqrt{2(\sin\alpha + \sin\beta)\cdot f(\epsilon, \varphi_\beta)}\right] \qquad (16)$$

$$K_w = \frac{\left(\frac{\pi}{2} - \beta\right) + \sqrt{2(\sin\alpha + \sin\beta)\cdot f(\epsilon, \varphi_\beta)}}{\cos\beta - \sqrt{2(\sin\alpha + \sin\beta)}.[f(\epsilon, \varphi_\beta) - 2e(\epsilon, \varphi_\beta)]} \qquad (17)$$

where α = the angle termed the "loop angle", i.e., the angle that the tangent to the centre point of the loop makes with the line of the wales.

β = the angle termed the "interlocking angle", i.e., the angle that the tangent to the loop at the interlocking point makes with the vertical.

$\epsilon = \sin(\pi/4 + \alpha/2)$

$\epsilon \sin\varphi = \sin(\pi/4 + \theta/2)$

θ = the angle that the tangent to the loop at point as T(x,y) makes with the positive direction of the Y-axis (i,e., the line of the wales).

They also determined the force "P" required to hold the loop in its equilibrium configuration, and the bending moment "M" at the interlocking points in terms of dimensionless parameters as follows:

$$\frac{P.\ell^2}{B} = 8K_c^2(\sin\alpha + \sin\beta) \qquad (18)$$

and $$\frac{M \cdot \ell}{B} = 4K_c(\sin\alpha + \sin\beta) \qquad (19)$$

where B= flexural rigidity of the yarn

Thus, it may be concluded from this analysis that the plain knit structure is completely specified by the values of two angles, α and β. The former determines the actual shape of the loop, while the other determines the point on the loop at which interlocking occurs.

In part two of their paper[18] they extended the two dimensional analysis to three dimensions by considering the applied couples acting perpendicular to the plane of the fabric. Throughout this work they assumed that:

i) the relaxed knitted loop is a perfectly symmetrical structure;

ii) that the yarn diameter remained a constant value along the length of the loop;

iii) that the forces and couples acting on the loop were localized at the interlocking points.

Another theoretical analysis of the plain knitted structure was reported in 1970 by Shanahan and Postle[19] where a more sophisticated solution to the same problem was given based on essentially the same assumptions as the previous work[20, 18]. In this work, instead of empirically fitting the model, the loop configuration was derived from a consideration of the reaction forces and couples acting within the structure, their magnitude being determined by the yarn displacement necessary for loop interlocking. Another feature of this analysis was that the approximation used in the previous study[18] in determining three-dimensional bent and twisted shapes was replaced by a more exact method. Then, they derived the following equations for loop length and fabric dimensions:

$$\ell = 4[S_B + R(\frac{\pi}{2} - \epsilon)] \qquad (20)$$

where $S_B = \frac{\lambda}{\sqrt{2p}} \cdot c{\cdot}d^{-1} \sqrt{\frac{-(\text{Cos}\,\alpha + \text{Sin}\,\epsilon)}{(\text{Cos}\,\beta - \text{Cos}\,\alpha)}}$

p= the repeat distance in the course direction

$\lambda = \frac{2}{\sqrt{\text{Cosh}\,\gamma - \text{Cos}\,\alpha}}$

$c{\cdot}d^{-1}$ = a Jacobean elliptic function[21]

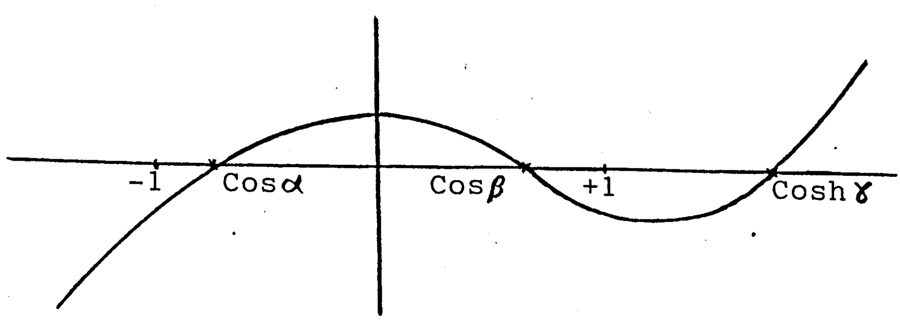
Cosα, Cosβ and Coshγ = three roots of the polynomial which can be represented by the curve shown in Figure(2.1)

$R = \frac{B}{M}$

B= flexural rigidity of yarn

M= couple acting at interlocking point

ϵ= the actual value of the interlocking angle.



Figure(2.1) The three roots of the polynomial are Cosα, Cosβ, and Coshγ.

$$K_c = \frac{4[S_B + R(\frac{\pi}{2} - \epsilon)]}{P} \tag{21}$$

$$K_w = \frac{[S_B + R(\frac{\pi}{2} - \epsilon)]}{R \cos \epsilon - z_B} \tag{22}$$

They also indicated, in this study, that, there is a minimum energy configuration for all relaxed plain knitted fabrics, and that this minimum energy is independent of the fabric tightness and of the physical properties of the yarn from which the fabric is knitted. In practice, the actual minimum energy is quite shallow, so that some deviations from this result are to be expected.

The above model was criticised by Hepworth et al[22] and Hepworth and Hepworth[23] published a solution to the same problem that differed considerably from that by Shanahan and Postle. They felt that the assumptions made in that analysis[19] were not compatible. They also indicated that an energy term was omitted from the equations, a fact which given such a shallow minimum energy might have greatly altered the results.

Shanahan and Postle[24] replied to the criticisms which were made by Hepworth et al, saying that although those two analysis[19,24] were based on somewhat different assumptions, they considered that the conclusions were quite similar. However, they accepted that a more exact analysis containing detailed consideration of the contact region would be of value, but they felt that their approximate assumptions used about the contact region between yarns in adjoining loops were reasonable and that they were further justified by the results obtained.

According to previous theoretical analysis presented by Shanahan and Postle[19], jamming should not occur in normal or loosely constructed plain knitted fabrics. Thus, they attempted in other studies[25] to analyze, by mechanical means, a general geometrical model for relaxed plain , rib and interlock knitted structures under both width and length jamming conditions. The conclusion was that the slack plain knitted structure should not be jammed in either length or width, but for very tight structures both length and width jamming will occur or at least be closely approached, and in some cases(e.g.,for relatively bulky yarns) jamming of tight structures may occur in practice. For the 1X1 rib structure, it was shown that it is an inherently width jammed structure.

II.2 Previous Work On 1X1 Rib Structures

The study of 1X1 rib knit structure has been reported in a few papers, the first of them being credited to Nutting and Leaf's[16] investigation when they proposed a generalized geometry for all weft knitted structures. They suggested that, in a relaxed state, and for more complicated structures other than plain knitted ones, the relation between courses per unit length and loop length are not of so simple a form as Equation(2), but it would contain a term involving the yarn diameter. Thus, they proposed a general equation of the following form:

$$\frac{1}{C} = A.\ell + D.T^{\frac{1}{2}} \qquad (23)$$

where ℓ= the length of yarn associated with one needle.

T= yarn linear density (Tex)

A and D= constants

Empirical results showed that values of "D" were significantly different from zero for structures as 1X1 rib, interlock and double pique in the different relaxed states. This indicated that yarn diameter($d \propto \sqrt{T}$) is a significant factor in determining fabric dimensions, contrary to Munden's[10] basic concept. However, they suggested that from a commercial point of view the values of "D" can be neglected for practical purposes, thus, the following simple equation can be used to describe the geometry of a fairly wide range of fabrics:

$$\frac{1}{C} = A.\ell \qquad (24)$$

However, the new values of "A" to be used in practice would be different and are given in the Table(2.3).

A more detailed investigation on 1X1 rib structures was studied and explained by Smirfitt[26] in 1965. He suggested the following relationships for these structures by analogy with the geometry of plain knitted fabrics (Munden's suggestions[10], the effects of yarn diameter were ignored:

$$c = \frac{K_c}{\ell} \tag{25}$$

$$r = \frac{K_r}{\ell} \tag{26}$$

$$s = \frac{K_s}{\ell^2} \tag{27}$$

where ℓ= yarn length in one single rib loop

c= courses/unit length

r= ribs/unit length

K_c, K_r, and K_s= dimensionless constants.

Fabric type	Fibre type	Average value of "A"
plain	wool	0.199
plain	cotton	0.181
plain	staple nylon	0.197
plain	acrylics	0.199
double piqué	wool	0.206
interlock	cotton	0.182
1X1 rib	wool	0.201

Table(2.3)

He attempted to establish the construction of a geometrical model of the 1X1 rib structure, using values based on the Leaf[15] model of the plain loop.He concluded the following equations by comparing the empirical equations for course and wale spacings in wet relaxed plain fabrics with those for course and rib spacings in 1X1 rib fabrics:

plain $\begin{cases} 1/c = (0.189).\ell & (28) \\ 1/w = (0.244).\ell & (29) \end{cases}$

1X1 rib $\begin{cases} 1/c = (0.200).\ell & (30) \\ 1/r = (0.313).\ell & (31) \end{cases}$

Then, he assumed that the face loops are the same shape in plain and rib fabrics, and the straight line link distance is the same as the link distance in Leaf's model, then relying on empirically established "K" values, he suggested the following equation for course spacing and rib spacing:

$$1/c = (0.189).\ell \qquad (32)$$

$$1/r = (0.150).\ell + (0.412).\ell.\mathrm{Sin}\,\theta \qquad (33)$$

where θ is the angle between the linking portion of a face and back loop and a perpendicular to the plane of the fabric. When $\theta = 23^{o}$ this equation reduced to the observed rib spacing (Equation 27).

Smirfitt observed that the best fit lines on the graphs of "c" and "r" (for the wet relaxed fabric state) plotted against $\frac{1}{\ell}$ possessed statistically significant intercepts of opposite sign in all cases and that these intercepts increased as relaxation progressed. When stitch density, S= c.r , was plotted against $\frac{1}{\ell^2}$, the intercepts on the S-axis were relatively small. He suggested, therefore, for most practical purposes, the intercepts could be ignored, and a sufficiently accurate prediction of fabric dimensions may be obtained. He also calculated various parameters, including fabric thickness, on the basis of Leaf's model of the plain knitted loop, and the weight per unit area in the same way as for plain knitted fabrics[10].

Another investigation was reported by Natkanski[27]. He also observed significant intercepts of the type described by Smirfitt when he analaysed his experimental data for 1X1 rib structures, and he found "K" values for a washed and relaxed fabric state. In addition, a theoretical model was derived by him on the geometrical shape of such structures, which was based on the elastica approach of Postle and Munden[18]. The resultant of his two dimensional model indicated poor agreement with the experimental "K" values, thus his model did not represent the true rib stitch in relaxed form.

Knapton, et al[28] concentrated their attention on 1X1 rib structures to formulate a theory which will best describe the dimensional properties of these weft knitted fabrics. They suggested that Smirfitt's equations did not satisfactorily explain the dimensional behaviour of a weft knitted structure, and suggested that the intercepts found by Smirfitt were due to incomplete relaxation. They also suggested that yarn diameter had no effect on the dimensional behaviour of the rib knitted structure.

They suggested the following equation:

$$\frac{1}{c} = a_c^p \cdot \ell \qquad (34)$$

$$\frac{1}{r} = a_r^q \cdot \ell \qquad (35)$$

where "p" and "q" are not equal to unity, more adequately satisfied the observed experimental relationships. However they suggested that p=q=1 in the fully relaxed state. They concluded from their experiments that with proper relaxation procedures,the dimensional properties of the 1X1 rib structure can be generalized by Munden's[10] model of the plain knitted loop structure without any modifications. They showed also that, the stitch density of the 1X1 rib structure in its fully relaxed state is dependent only on loop length, and is independent of yarn content, structure and system of knitting, and this is similar to Doyle's theory[8] on the plain knitted structure.

II.3 Previous Work On Double Jersey Structures

Later, Knapton[29] recommended the following definitions in order to obtain a standard notation to be used for the dimensional fabric parameters encountered in double jersey structures:

He suggested that in these structures the fundamental unit of structure was the structural knit cell (SKC). He also, described as the structural cell feed, the number of machine feeds required to knit one structural knit cell.

Therefore:

$$l_u = \frac{\dfrac{\text{Length of yarn knitted at one structural cell feed}}{N}}{\text{in one revolution X } (n_w)} \qquad (36)$$

$$C_u = \frac{\text{(Number of machine revolutions) X (number of structural cell feeds)}}{\text{Average fabric length}} \quad (37)$$

$$W_u = \frac{N}{(n_w) \text{ X (Average fabric width)}} \quad (38)$$

where l_u = structural cell stitch length (SCSL).

C_u = course units per unit fabric length.

W_u = wale units per unit fabric width.

N = total number of needles in the machine.

n_w = number of needles forming the width of the structural knit cell.

For example, the SKC of a 1X1 rib structure consists of two single loops and that for interlock of four, etc.

According to the above definitions, Knapton modified the equations of Munden to the following forms:

$$U_s = C_u \cdot W_u \cdot (l_u)^2 \quad (39)$$

$$U_c = C_u \cdot l_u \quad (40)$$

$$U_w = W_u \cdot l_u \quad (41)$$

$$U_r = \frac{U_c}{U_w} = \frac{C_u}{W_u} \quad (42)$$

where $S_u = C_u \cdot W_u$ is a measure of the fabric stitch density.

Further parameters were concluded as follows:

$$\frac{\text{weight of fabric}}{\text{running m.}} = 0.1n_w . U_c . \text{Tex} \quad \text{(gram)} \qquad (43)$$

$$\text{weight of fabric/m}^2 = \frac{0.1U_c . \text{Tex}}{l_u} \quad \text{(gram)} \qquad (44)$$

$$\text{fabric width} = \frac{N . l_u}{n_w . U_w} \quad \text{(Cm.)} \qquad (45)$$

The above symbols, i.e., U_s, U_c, U_w and U_r covered the whole range of knit structures and not specifically the plain knit structure.

Woolfardt and Knapton[30] introduced a three dimensional loop model for 1X1 rib "SKC" based on several simplifying assumptions relating to the geometrical configuration of the knitted stitch as follows:

i) Contrary to the observations of Smirfitt[26], loops of adjacent wales touch at their widest parts.

ii) The narrowest and widest parts of any two interlocking loops in the same wale coincide.

iii) The loop shape in the fabric plane is that of an elastica.

iv) The linking portions joining the face and back loops to each other are at right angles to the face and back surface planes.

v) The narrowest part of the loop shape approximates to two yarn diameters.

Examination of photographs of 1X1 rib fabrics knitted from different yarns to different degrees of tightness under tumble relaxed condition revealed these assumptions to be reasonable.

Since the three dimensional length analysis was complicated, they attempted to determine "l_u" on the portions of the SKC which are curved in essentially one plane only. From this analysis they found the following parameters for the SKC of a 1X1 rib structure:

$$\frac{1}{C_u} = 2b.K.\text{Cos}\,\varphi_m \tag{46}$$

$$\frac{1}{W_u} = 2b[\{2E(K,\varphi_m) - F(K,\varphi_m)\} + \frac{1}{3}(2E(K,\frac{\pi}{2}) - \ldots F(K,\frac{\pi}{2})] \tag{47}$$

$$l_u = 8b.F(K,\frac{\pi}{3}) \tag{48}$$

$$U_s = \frac{16[F(K,\frac{\pi}{3})]^2}{K.\text{Cos}\,\varphi_m[\{2E(K,\varphi_m) - F(K,\varphi_m) + \frac{1}{3}2E(K,\frac{\pi}{2}) - \ldots F(K,\frac{\pi}{2})\}]} \tag{49}$$

$$U_c = \frac{4F(K,\frac{\pi}{3})}{K.\text{Cos}\,\varphi_m} \tag{50}$$

$$U_w = \frac{4F(K,\frac{\pi}{3})}{[2E(K,\varphi_m) - F(K,\varphi_m)] + \frac{1}{3}[2E(K,\frac{\pi}{2}) - F(K,\frac{\pi}{2})]} \tag{51}$$

$$\frac{U_c}{U_w} = \frac{[2E(K,\varphi_m) - F(K,\varphi_m)] + \frac{1}{3}[2E(K,\frac{\pi}{2}) - F(K,\frac{\pi}{2})]}{K.\text{Cos}\,\varphi_m} \tag{52}$$

where $b^2 = \frac{R}{P}$

R= flexural rigidity of rod (yarn),

P= the magnitude of two equal and opposite compressive forces applied at the end of loop ,

$K = \cos \frac{\theta}{2}$,

θ= the angle between the tangent at narrowest point of loop and the X-axis ,

$\sin \varphi_m = \frac{1}{K\sqrt{2}}$

φ_m = the value of φ at the widest point of loop ,

$F(K,\varphi_m)$ and $E(K,\varphi_m)$= elliptical integrals of the first and second kind, respectively, with modulus "K" and amplitude "φ_m".

Woolfardt and Knapton plotted non-dimensional C_u, W_u and S_u parameters in the fully relaxed state against $\frac{1}{l_u}$ and $\frac{1}{l_u^2}$ respectively, and showed that these parameters are constant with changes in "l_u". Consequently, they suggested that their fully relaxed wool rib fabrics behaved essentially like Munden's[10] plain knitted fabrics. These, relationships, therefore, exhibited with best fit lines a high significant correlations but nonsignificant intercepts.

More recently, definitions were recommended by Burnip and Fahmy[31], in order to determine the dimensional parameters of double jersey structures. They suggested that in these structures, it was convenient to determine formulae derived from Munden's equations[10], modified to take account of the above factors. Thus, the following new concepts were defined:

$\bar{\ell}$ = Average loop length

$$= \frac{\text{Total loop length in the structure}}{\text{Number of needles in action in the structure}} \qquad (53)$$

$\bar{C}$ = Average courses/cm.

$$= \frac{\text{[Total number of courses/structure (face and back)] X (Number of structural length/cm.)}}{2} \qquad (54)$$

$\bar{W}$ = Average wales/cm.

$$= \frac{\text{[Total number of wales/structure (face and back)] X (Number of structural widths/cm.)}}{\text{Average number of courses/structure}} \qquad (55)$$

According to these new definitions, Burnip and Fahmy modified the Munden's original equations as the following:

$$\bar{S} = \bar{C} \cdot \bar{W} = \frac{K_s}{\bar{\ell}^2} \qquad (56)$$

$$\bar{C} = \frac{K_c}{\bar{\ell}} \qquad (57)$$

$$\bar{W} = \frac{K_w}{\bar{\ell}} \qquad (58)$$

where $\bar{S}$ is an average measure of the fabric stitch density.

II.4 Previous Work On Interlock Structures

Relatively little work have been done on the geometrical analysis for interlock structures compared with that on plain and rib fabrics.

Hurt[32] introduced a loop model for the wet relaxed cotton interlock structure, based on the separation of the structure into various sections. This model indicated that fabric dimensions i.e., wale spacing ($1/W_i$) and course spacing ($1/C_i$) will be effected by both length of yarn knitted into loop (l_i) and yarn diameter and related to cotton count. He expressed the following equations to describe his fabrics, where:

$$100 \frac{1}{W_i} = 13.4\ l_i + 10.8 \frac{1}{\sqrt{\text{count}}} - 0.86 \qquad (59)$$

$$100 \frac{1}{C_i} = 20.4\ l_i - 2.92 \frac{1}{\sqrt{\text{count}}} + 0.235 \qquad (60)$$

A reasonable correlation between these equations and the experimental results was obtained.

CHAPTER III

PREVIOUS WORK ON THE EFFECT OF RELAXATION TREATMENTS ON THE STABILITY AND DIMENSIONAL PROPERTIES OF COTTON WEFT KNITTED FABRICS

III.1 Dimensional Stability Of Cotton Fabrics During Wetting, Washing And Laundering

A study of the dimensional changes of plain and rib cotton knitted fabrics was undertaken by Fletcher and Roberts[13], to obtain basic information regarding the stretching and shrinking of these materials when laundered. They showed that when the wale spacing data for the laundered goods were plotted against course spacing data, a parabolic curve was obtained. Therefore, the data were fitted to a quadratic equation using the general form for a parabola:

$$p^2 = a(w + b) \qquad (1)$$

where p= course spacing

w= wale spacing

In this study they found that:

i) The amount of yarn shrinkage in the fabrics is negligible, during laundering (usually less than 1% for the plain and rib finished fabrics, and between 1% to 3% for the gray fabrics), and therefore concluded that the yarn shrinkage had little effect on the dimensional change of the fabric.

ii) The least dimensional change, in both the plain and rib cotton knitted fabrics, appeared in those so finished that the wale and course spacings followed a parabolic relationship.

iii) The most shrinkage in area occured in the tightest knitted fabrics. In some of the knit fabrics the increase in width was greater than the decrease in length so that the area of the laundered fabric exceeded that of the original specimen.

Collins[33] suggested that yarn swelling was the principal factor of shrinkage in cotton woven fabrics. He assumed that, since the yarn shrinkage during relaxation is slight, the fabric shrinkage, therefore, must occur in the structure of fabric, because, when the fabric is wetted the yarn will be swollen; thus a greater length of warp yarn will be required to interweave the increased diameter of the filling yarns. Since, such an extra amount of yarn is not available in the fabric structure, this must result in a length shrinkage.

In knitted fabrics the configurational change of loops due to yarn swelling is much more complicated than for woven fabrics, because of the distinct three dimensional feature of the knitted loop. Moon Won Suh[1] applied a similar approach to explain the shrinkage of cotton plain knitted fabric, using a geometrical analysis of the loop reorientation resulting from yarn swelling. Using a loop model where he assumed that the yarn had a circular cross section and was of a uniform diameter and the curved portions of the loop were assumed to be arcs of a circle. Based on this model he came to the conclusion that the measured shrinkage of knitted cotton fabric after wetting and drying could be explained by two factors:

i) increase in course curvature (brought about by yarn swelling);

ii) loop migration, i.e., change in loop shape as a result of the swelling of the fibre.

He also suggested from his experimental work that an increase in stitch length resulted in a higher shrinkage due to migration and a lower shrinkage due to curvature change, but the additive effect of both shrinkages was such that, in all cases, the total shrinkage increased with increase in stitch length.

Burnip and Saha[34] investigated the dimensional properties of cotton fabrics knitted from open-end-spun yarns and compared them with fabrics made from ring-spun yarns. They showed that fabrics knitted from the two types of yarn possess different properties and particularly, the amount of relaxation shrinkage that occurs when open-end-spun yarn is used is greater than that which occurs in fabrics knitted from ring-spun yarns.

Burnip and Elmasri[35] investigated the geometrical and dimensional properties of close-eyelet cotton fabrics. They attempted to relate the various geometrical parameters of this structure to its loop length in both the dry and wet relaxation treatment. In their work, the courses have been divided into two distinct types:

a) plain course which consists only of plain loops;

b) gather course which consists of two plain loops plus the transferred loops.

For all samples they found a constant difference between the plain course loop length and the gather course loop length. Therefore this constant shows that the fabric dimensions can be related to the length of the plain loop (l_p) in the structure.

They found that to bring the eyelet fabric to its stable state,both dry and wet relaxation treatments are insufficient, and consequently, distortion of the structure is still present after these treatments. They showed that the more stable fabric dimensions were obtained after a dynamic wet treatment (i.e., washing treatment).

They showed that the plotted graphs of the eyelet courses/inch (e_c) and eyelet wales/inch (e_w) against the inverse of plain loop length ($1/l_p$) and of the eyelet density (E) against ($1/l_p^2$) are similar in form to that obtained for plain fabric, and obtained the equations relating these variables given in Table(3.1).

Additionally Burnip and Abbas[36] who investigated the dimensional properties of knitted fabrics made from cotton blended with a range of man-made fibres came to a similar conclusion that, to obtain a fabric in a fully relaxed state a washing and tumble dried relaxation treatment was necessary. An important result from this work was to suggest the formula for stitch density for fabrics knitted from blended fibre yarns and for a given blend ratio, which enabled values of "K_s" to be determined for any blend

Relaxation	Regression Equation	Significance Of Intercept	Correlation coefficient	Best-fit line through origin
Dry	$e_c = \frac{1.25}{1_p} - 0.5$	N.S.	0.942	$e_c = \frac{1.20}{1_p}$
	$e_w = \frac{0.45}{1_p} + 6.9$	* *	0.581	$e_w = \frac{1.77}{1_p}$
	$E = \frac{1.55}{1_p^2} + 15.6$	*	0.978	$E = \frac{2.10}{1_p^2}$
wet	$e_c = \frac{1.75}{1_p} - 2.5$	N.S.	0.971	$e_c = \frac{1.28}{1_p}$
	$e_w = \frac{0.64}{1_p} + 6.2$	* *	0.797	$e_w = \frac{1.83}{1_p}$
	$E = \frac{1.85}{1_p^2} + 12.3$	N.S.	0.980	$E = \frac{2.28}{1_p^2}$
washed	$e_c = \frac{1.50}{1_p} + 1.0$	N.S.	0.940	$e_c = \frac{1.70}{1_p}$
	$e_w = \frac{2.14}{1_p} - 2.7$	N.S.	0.994	$e_w = \frac{1.63}{1_p}$
	$E = \frac{3.27}{1_p^2} - 13.1$	N.S.	0.994	$E = \frac{2.80}{1_p^2}$

Table(3.1) Regression Equations for Cotton Eyelet

** significant at 1% level.

* significant at 5% level.

N.S. Not significant.

composition in a given state of relaxation. It is possible to predict the "K_s" values from the following equation:

$$S = \frac{K_s(\text{cotton}) + B[K_s(\text{mmf}) - K_s(\text{cotton})]}{\ell^2} \qquad (2)$$

where s= stitch density;

ℓ= stitch length;

B= the man-made fibre blend ratio(expressed as a fraction);

K_s(mmf)= the value of "K_s" for the fabric knitted from 100% man-made fibre yarns;

K_s(cotton)= the value of "K_s" for the fabric knitted from 100% cotton yarns.

They suggested that for the wide range of blends considered it was found that fabric thickness was independent of fabric stitch length. They also found that although in some cases there was a statistically significant difference between the line passing through the experimental results of fabric dimensions and the line passing through both the results and the origin, for most practical purposes "K" values determined from the slope of the line passing through the results and the origin could be used with confidence in the prediction of fabric width and area density.

Poole and Brown(37) worked on the rib fabrics from cotton and cotton-blend yarns which were treated to a variety of relaxation treatments and found the following results:

i) The behaviour of 1X1 rib fabrics is very similar to single jersey fabrics when subjected to relaxation treatments. Therefore in wet relaxation the cotton fabrics obtained greater shrinkage than synthetic fibre fabrics, and blends of the fibres gave intermediate results exactly related to their blend composition. This persists through washing and compares with the findings of Burnip and Abbas[36] for jersey fabrics.

ii) Hot-dry treatments have the opposite effect, i.e., the cotton fabrics have the lower "K_s" values than synthetic fibre fabrics.

iii) The relaxation shrinkage is very sensitive to fibre type, while consolidation shrinkage appears to be independent or only slightly affected by the blend constitution of cotton/polyester fabrics.

iv) Cotton rib fabrics attain similar "K" values (see Table(3.2)) to those reported for wool fabrics as may be seen in Table(3.3), where the results of several workers recalculated in terms of "K" parameters are given.

	Dry-relaxed	Wet-relaxed	Tumbled 60 minutes	Washed 60 minutes
K_s	11.70	14.19	12.78	15.31
K_c	4.10	2.41	4.39	5.09
K_w	2.85	2.95	2.91	3.00
K_r	1.44	1.63	1.51	1.70

Table(3.2) "K" values for 1X1 rib cotton fabric.

(Poole and Brown)

	(27) Natkanski	(26) Smirfitt	(28) Knapton	(30) Woolfardt	(38) Fong
K_s	16.90	16.65	15.92	15.67	15.95
K_c	5.35	5.30	5.30	5.35	5.55
K_w	3.16	3.14	3.01	2.92	2.88
K_r	1.69	1.69	1.76	1.84	1.92

Table(3.3) "K" values for 1X1 rib wool fabric.

For the wool plain jersey structure, Knapton[39] suggested that the wet relaxed state previously found by Munden[10] of which a "K_s" value of 21.6 had been proposed, was in fact not a stable relaxed state, but only a stage on the way to full relaxation (i.e.,that obtained after ten washings and tumble dryings) where a "K_s" value of 23.6 was found to apply, and where constant "K_c" and "K_w" values are obtained.

Knapton, Aziz and Truter[5], in their investigation on the dimensional properties and stabilization of the cotton plain knitted fabrics followed the earlier work of Knapton[38] and others, in considering the stable configuration of the knitted loop structure.

Previously Knapton[38] had shown that wool fabrics which had been shrink-resisted only attained a stable configuration from which no further shrinkage occurred after the tenth laundering.

Knapton[5], et al, found almost identical results when considering the dimensions of cotton plain knit fabrics after washing and tumbling treatments. They found that after these treatments the "K_c" and "K_w" values were relatively constant, and that the "K_c" value showed slightly more variation than "K_w".

Virtually all of these experimental investigations, have come to the same conclusion, that if the fabric can be obtained in a truly relaxed state, the "K" values of the fabrics are independent of the stitch length. In contrast the fabric dimensional behaviour predicted by the force analysis models of Postle and Shanahan[(19)] and Hepworth and Leaf[(22)], predict significantly different "K" values from those found in experiments and also predicted a significant change in "K" values with change in fabric tightness.

Munden and Postle[(18)] have suggested these apparent differences between experiment and theory can be explained by the fact, that in fabric form, the effective diameter of a yarn varies approximately linearly with change in stitch length whereas the theoretical models made no allowance for any changes in yarn diameter as a result of change in knitting tightness or relaxation treatment.

Knapton and Yuk[(40)] have also reported on the dimensional properties of Punto-Di-Roma double jersey fabric knitted from cotton yarns. They observed surprisingly large linear shrinkage after dry cleaning (commercial dry cleaning with perchloroethylene, 15 minutes cycle). The rate of change in area decreased with an increasing number of dry cleaning cycles and after five consecutive cycles, the shrinkage was negligible.

They also investigated the effect of mercerization treatments on the dimensional properties of the fabric and found that these treatments cause a large average shrinkage in "l_u", the effect being more noticeable in slack fabrics than in tight fabric constructions. This effect is explained by the fact that the chemical treatment causes yarn bulking and extensive molecular rearrangement within the fibres. In contrast the high dry cleaning shrinkage of the un-mercerised fabrics is attributable to the release of the mechanical set imposed in the yarn at the knitting stage.

Somashekar and Elder[(41)] investigated the effects of different washing and drying relaxation treatments, of increasing severity in terms of time, temperature, and agitation (mechanical action) on the weft knitted cotton fabrics.

They showed that wetting and subsequent increasing severity of washing conditions and the repeated washing caused the increase in area shrinkage and thickness, and a decrease in the air permeability. These results suggested a progressive consolidation and three dimensional relaxation of the material. They indicated that the manner of drying is an important factor. For example, in the tumble drying method, the fabrics obtain a more stable state than the drying of fabrics in the open air. In tumble drying, the inter yarn frictional effects at loop interlocking points are overcome, and the forces at these points are reduced to low levels, indicated by low frictional restraints, which have given a higher stability.

Parker[42] investigated the effect to which both loop length and yarn count determine the effect of knitting and finishing variables on the stability and shrinkage of cotton interlock fabrics. He showed that with longer loop length the strain of the fabric was increased in the wale direction and was accompanied by a corresponding decrease in course direction in both knitting and finishing strains. He found, also, that the maximum length distortion occurs in Winch scouring and is accompanied by a corresponding reduction in width. It also revealed that at both the drying and calendering stage, considerable area distortion may be introduced.

III.2 Dimensional Stability Of Cotton Fabrics Due To Chemical Stabilising Treatments

It has been known that a degree of shrinkage control for cotton knitted fabrics can be achieved by chemical finishing, and this is one of the main reasons that most cotton outerwear knits are finished chemically.

Irvine[43] investigating cotton knitted fabrics reported that chemical crosslinking agents could reduce the shrinkage of knitted fabric by about half, which makes a significant improvement to their wash-wear appearance, preserves the surface appearance of the fabrics through laundering, and would also provide a pronounced improvement in the crease resistant properties of the fabrics. On the other hand, he also revealed that the use of the chemical stabilizers, as in woven fabrics, caused losses in knitted fabric strength and abrasion.

Black[44] investigated the effect of knitting tightness and finishing treatments involving heat setting and chemical finishing on cotton and cotton/polyester blends. He reported that in the industry, the practice has been to move to cotton/polyester blends, in which the polyester is used primarily to help retain the strength and abrasion characteristics of the knitted fabric after crosslinking and that a blend of the order of 70/30 cotton/polyester was considered to give a good balance of properties. His work indicated that shrinkage values of less than 3% could be obtained by careful selection of chemical treatments and heat setting with controlled knitting and finishing processes.

Knapton et al[5] also showed that the "K" values after mercerising treatment are almost identical with those found after washing and tumble drying treatment. The data of the mean "K" values for various conditions are shown in Table(3.4).

Fabric Treatment		K_c	K_w	K_s
Mechanical	M	5.73	4.10	23.49
Chemical	C	5.63	4.02	22.63
Chemical followed by Mechanical	CM	5.76	4.10	23.62

Table(3.4) Mean K-parameters for various fabric conditions.

This Table shows that the "K_s" value for chemical treatment (C) is lower than that for the mechanical treatment(M). However, after the fabric had been subjected to a laundering cycle after chemical treatment(CM), the "K_s" value is similar to that obtained by tumble drying the non mercerised fabric. These results suggest that the relaxed configuration of the fabric is not affected by the mercerising process.

Frick and Verburg[45] reported that the laundry shrinkage in knitted fabrics of cotton and cotton/polyester is reduced by a combination of chemical cross-linking and preshrinkage treatments. Preshrinkage is induced by compressive shrinkage either before or after crosslinking, and by dry or wet relaxation after crosslinking. In compressive shrinkage before crosslinking, the fabric is compacted by a mechanical action but, in the chemical method the cellulose of the cotton is crosslinked as in wrinkle-resistance of cotton.

In their investigation the following points were observed:

i) The strength of fabric in a relaxation process after crosslinking is greater than with compaction before or after crosslinking.

ii) the reduction of laundry shrinkage by preshrinkage before crosslinking requires a greater loss of fabric dimensions than the reduction by compression after crosslinking.

iii) All methods of induced preshrinkage usually affected the increase in stability from crosslinking adversely. The compaction process before crosslinking, usually, has a less detrimental effect than relaxation after crosslinking.

They suggested that to reduce laundry shrinkage to a given level, the method of preshrinkage and the extent of crosslinking, that will give the least objectionable adverse effects to the finished fabric, should be chosen. However, crosslinking followed by a relaxation treatment appears most attractive for general use.

Greenwood[46] reported the effect of a piece mercerizing process on cotton weft knitted fabrics. Some of his conclusions are given below:

i) The structure of the fabric is changed permanently by the mercerizing process.

ii) The applied tension during mercerizing treatment to increase the lustre needs to be kept to a minimum. During this treatment the fabric will be stretched in length and may also shrink in width and, these deformations will be set into the fabric by this treatment.

iii) The dimensional stability of the fabric will be improved by mercerizing.

iv) Bursting strength is also improved by mercerizing.

He reported, also, that a resin finishing process after piece mercerizing treatment on cotton knitgoods can produce good dimensional stability with a much improved fabric strength.

CHAPTER IV

PREVIOUS WORK ON THE FABRIC'S AIR PERMEABILITY PROPERTY

The knowledge of the air permeability of fabric is important for many purposes such as, for example, suitability for use as vacuum cleaner bags, filters, parachutes, down proof covers, clothing, tent, etc.

Due to the manner in which yarns and knitted fabrics are constructed, in fact, a significant proportion of the total volume occupied by a fabric is its airspace. The distribution of this airspace affects a number of important fabric properties such as warmth and protection against wind and rain in clothing.

Clayton[47] investigated the relationship between the cover factor of woven fabric and air permeability, and found that this relationship is not, as might have been expected, a straight linear form. He showed that the permeability decreases at a constant rate as the number of picks per inch increases from 35 to 65, but as the number is increased, the permeability decreases become less, probably because all the holes in the cloth have been closed. He also found that the air permeability increased linearly with increased yarn twist factor. He reported that all the finishing processes he investigated tended to reduce the air permeability of the cloth.

Lord[48] described an instrument for measuring the air permeability of fabrics and its mode of operation. Then he investigated the effect of certain variables on the air permeability of the fabric. He found that the flow of air is proportional to the pressure drop for close fabrics, but with more open fabrics, flow is more nearly linearly related to the square root of the pressure drop. He also showed that, for the areas examined, flow is proportional to the area of specimen, and the air resistances of multilayers of fabric are proportional to the number of layers tested, up to five layers the maximum number tested.

Oxtoby[49] devised a method to measure the air permeability of open knitted fabrics by using superimposed fabric layers when difficulty would be experienced in making a direct measurement because of the open structure of the fabric. He suggested this proposed method is particularly applicable to the measurement of the air permeability of knitted fabrics, and other fabrics which have a high rate of air flow. He suggested that the advantage of using this method was that very stable readings can be obtained. In this method, an estimate of the rate of air flow for a single fabric layer may be obtained by extrapolation from a logarithmic scales graph of air flow and the number of layers. He also showed that the total air resistance (i.e.,the reciprocal of air permeability) of a composite of superimposed fabrics was almost the sum of the individual air resistances of each fabric.

Knapton and Lo[50] investigated the air permeability of a range of double jersey fabrics by both the single and multi-layer (P_s and P_m respectively) methods and found that there is little difference between the two, but the value of

"P_s", in general, is greater than "P_m".

They, also, found that there is a good inverse linear relationship between "P_s" or "P_m" and tightness factor(K), although the rate of decrease in "P_s" with "K" depended entirely on the structure being considered. The fabrics knitted with interlock gating were found to be generally more permeable than the once knitted with rib gating. They attributed this phenomenon to the fact that rib loop units in interlock gating are relatively widely separated allowing easy air movement. Tuck stitches in interlock gated structures open the fabric, thus the single-pique structure has the most permeability, due to the presence of the tuck stitches at every third dial course.

De Araújo[51] considered the relationship between the air permeability and the ratio, structural thickness/structural knit cell length (t_c/t_u) of cotton interlock fabrics and tightness factor (K). In considering the relationship between air permeability and t_c/t_u, he found that, in all states of relaxation considered, these two fabric variables are linearly correlated at a high level of significance. He also suggested that the main parameter controlling air permeability for fabrics of similar yarn characteristic is the tightness factor (K).

Kothari and Newton[52] investigated the air permeability of non-woven fabrics and found that the one factor most closely related to the air permeability is the fabric weight per unit area. They also found experimentally that the relation between the air permeability and the reciprocal of the fabric weight per unit area is almost linear. This relationship has been represented as following:

$$p_a = \frac{k_1}{w} + k_2 \qquad (1)$$

where p_a = air permeability

w = weight per unit area

k_1 and k_2 = constant values

Atwal[53] suggested that the amount of variation in air resistance of non-woven fabrics can be achieved by increasing the total exposed surface area of the fibres within the fabric and by decreasing the size of the channels within the fabric through which the air flows. Therefore any factor of fabric or fibre which affect these two properties will also affect the air resistance.

CHAPTER V

THE PARTICULARS OF THE MACHINES AND INSTRUMENTS USED IN THE EXPERIMENTAL WORK

V.1 General

This project was originally designed to investigate the effect and potency of both mechanical and chemical methods on the relaxation of all the main weft knitted fabric structures (i.e.,plain, rib and interlock) knitted from cotton yarns, and to find out the differences between the geometrical and dimensional properties of these fabrics with those knitted from other yarns,such as wool. In this work, the following types of circular weft knitting machine were used for the manufacture of the experimental fabrics.

V.2 Details Of Machines

a) Single Jersey Machine

To knit the plain fabrics, the Wildt Mellor Bromley type 4/S MHCS circular machine was used. This machine is a plain machine with a total of 1500 needles around it and has a gauge of 18 needles per inch. The diameter of this machine is 66 cm. and normally has 32 feeders (for the experimental work required for this thesis only eight of the feeders were fed by yarns). The machine is fitted with four types of electric stop motion; top dropper, bottom dropper, needle detector and fabric detector. They will detect a fault in machine, yarn or fabric. The machine was not equipped with a positive feed device, thus, the length of yarn used in a stitch can not be controlled positively. The feed must, of course, be equalised at all feeders by means of a yarn speed meter. The machine was set to produce a plain fabric.

b) Interlock Machine

To produce the interlock fabrics, the Mellor Bromley type 3/RL/3 circular machine was chosen. This machine is a cylinder and dial double jersey weft knitting machine with interlock gating. The diameter of this machine is 40.64 cm. and its cylinder and dial are each fitted with 1008 needles, consequently the total number of needles is 1008 X 2 = 2016. The machine gauge (needles per inch) is 20 and it has 12 feeders. Three types of electric stop motion have been fitted on the machine; top dropper, bottom dropper, and needle detector which will detect a fault in machine, yarn or fabric. The top droppers detect excessive yarn tension or breaks in the yarn between the cone and the positive feed. The bottom droppers operate between the feed wheels and the needles. These units will detect broken yarn or low yarn tension. Needle detectors are designed to stop the machine when a broken needle is found in the dial or cylinder or in the case of fabric imperfections causing a build up of yarn on the needles.

The regularity of fabric can be controlled by very fine adjustments to the amount of yarn fed to the needles by means of a trip-tape positive feed. The yarn is allowed to run between the trip-tape and a free revolving drum. The trip-tape is made of a material which will grip the yarn, and there is one revolving drum at each feed. The speed of the tape is governed by means of an adjustable pulley. The change of fabric quality can be obtained by changing the amount of yarn delivered which is determined by the speed of the tape.

c) Rib Machine

The rib samples, in this work, were knitted on the Teaching Machine type TM. This machine is in the first instance a rib machine with a convenient diameter of 30.48 cm. and a gauge of 10 needles per inch. The Teaching Machine is equipped with four feeders, interchangeable cylinder cams and a double track dial cam system with manually changeable cam positions. The cylinder and dial of this machine are each fitted with 396 needles. Equipment also includes a positive yarn feed system which is used for feeding yarn at a known and constant speed. After inserting the positive feed system, the stitch cams must be adjusted so that the yarn tension is also equalised. This machine has been equipped with conventional electric stop motions such as; feeder detector unit, top stop motion and needle detector. The functions of the feeder detector unit is to provide a safeguard for the yarn running from the positive feed wheel to the feeder. An interruption in the flow of yarn will cause the dropper to fall forward in an arc, and therby make an electrical contact inside the housing of the unit, causing the machine to stop. The stop motion unit will automatically stop the machine, if the yarn should drag excessively through the presence of knots or slubs on the bobbin, or if the flow of yarn is ceased altogether. Needle detectors operate as the same manner as explained for interlock machine.

V.3 The HATRA Yarn Length Counter

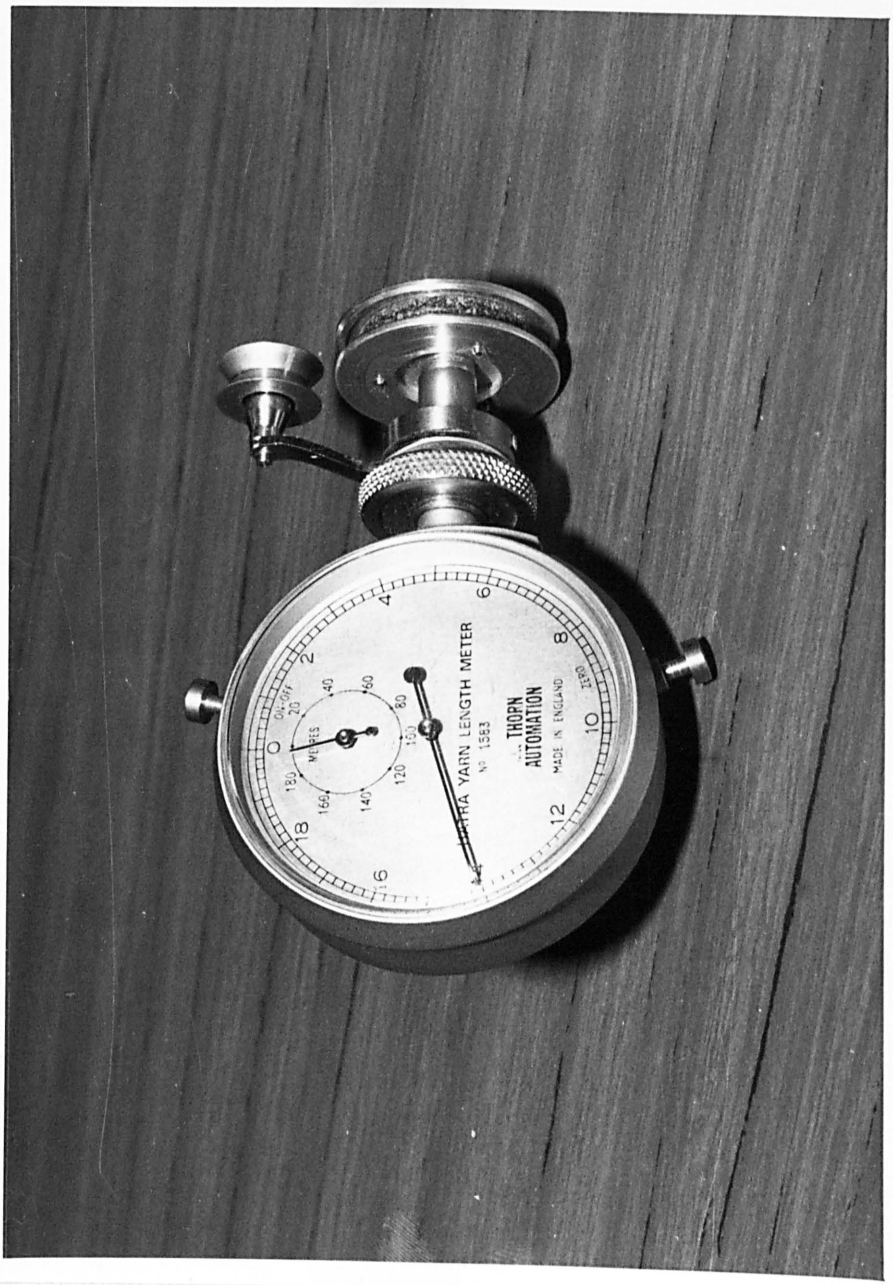
This instrument was used in order to measure the length of yarn being fed at each feeder (see Figure 5.1). From this figure it was possible therefore to calculate the length of yarn in one course, and hence the stitch length (ℓ).

V.4 The Zivy Yarn Tension Meter

In this work the Zivy yarn tension meter was used to detect the running tension of the yarn. The instrument shown in Figure (5.2), requires the yarn to be threaded as shown. In this condition the instrument is calibrated to record the yarn tension directly in grams.

V.5 Air Permeability Instrument

A number of instruments have been designed to determine the air permeability of fabrics such as the Gurley Densometer(54), the Frazier Air Permeability Apparatus(54) and the Shirley Air Permeability Apparatus(55). All of these have become recognised as standard air permeability testers. As mentioned previously, some of these peices of apparatus are

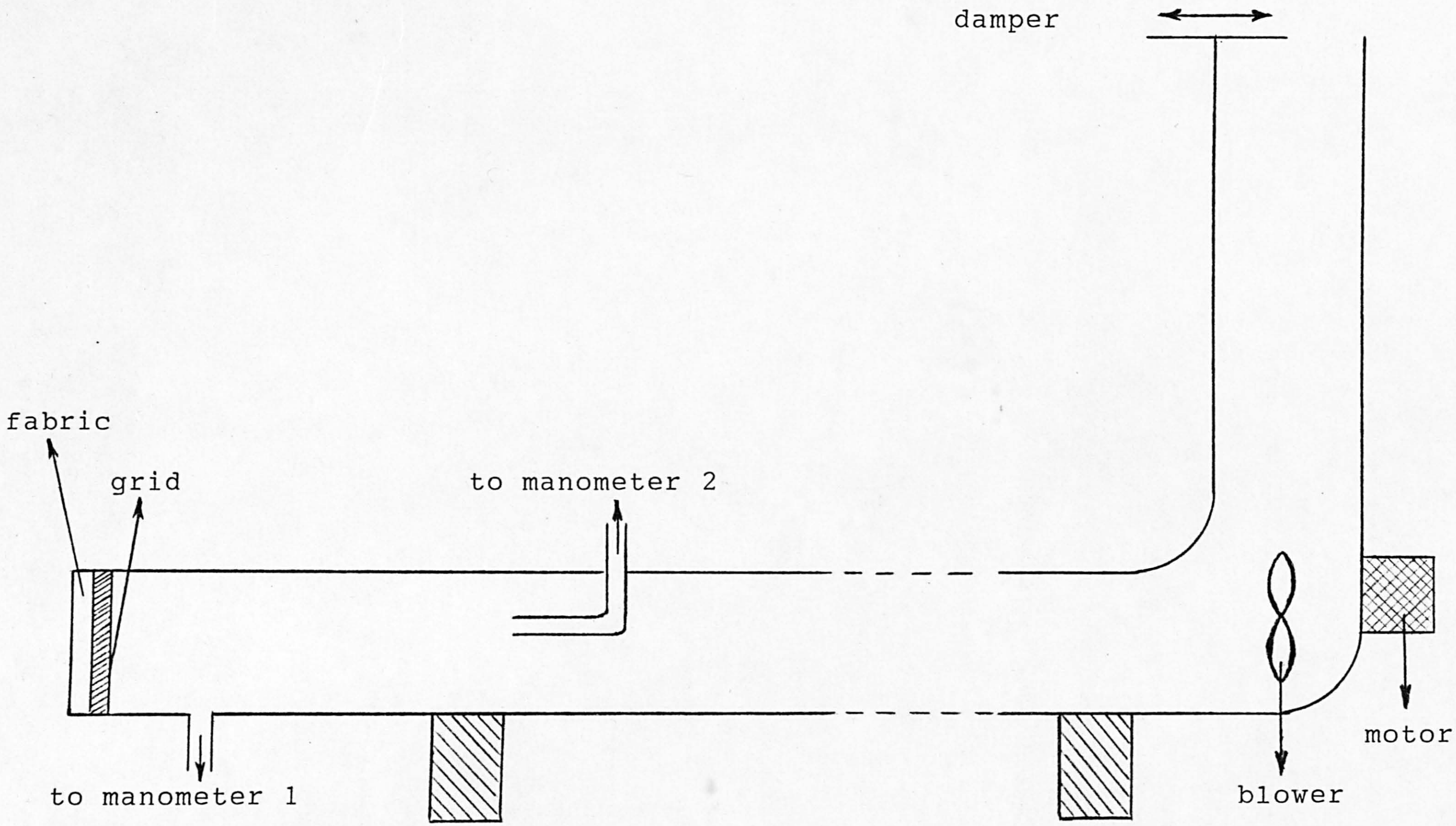


Figure(5.1) The HATRA Yarn Length Counter.

Figure(5.2) The Zivy Yarn Tension Meter.

ideal for the measurement of the air permeability of knitted fabrics, because of the high air permeability of these structures. A wind tunnel was used for the determination of air permeability in this work which had previously been found to be effective for the measurement of air permeability of knitted fabrics[56]. A schematic representation of this apparatus is shown in Figure (5.3). The manometer 1 measures the pressure difference between the two sides of the sample. The pressure difference was maintained at a constant value (normally 5 cm. of water for textile materials in this apparatus). The rate of flow is adjusted by moving the damper forward or backward, until the required pressure drop across the fabric is obtained.

The specimen to be tested was mounted on a metal grid containing square holes of size 1 cm. X 1 cm.. The grid was placed on the open end of the cylinderical tube. The air is drawn through the specimen by the operation of the suction pump and the manometers were positioned in such a way that they recorded the pressure drop across the specimen and this was maintained at a constant value. The air velocity value is measured directly by using an air velocity meter which is calibrated at an air temperature of 20°C and 760 mm. hg. Its principle is that the hot wire of manometer 2 is cooled by the air generated through the tunnel and gives a reading on the air velocity meter.



Figure(5.3) The schematic of the principle of the wind tunnel.

V.6 Scouring Machine

In order to scour the fabrics with caustic soda solution, pegg model K scouring machine, type PD 4831 was used. This machine has been manufactured to scour textile materials, but it can also be used for dyeing. It is a steam heated machine with maximum temperature 100°C and operates at atmospheric pressure. The liquor capacity is 80 litres and the liquid is agitated by an impeller in the base of machine. The diameter of the machine is 70 cm.. It works at two different speeds; slow and fast. The former is usually used for lighter materials, but the latter one, which is more normally used, is applied for normal materials (as used in this work).

CHAPTER VI

DESCRIPTION OF THE EXPERIMENTAL WORK

VI.1 Introduction

It was the intension in the main experiment to study:

i) the dimensional properties of weft fabrics knitted from cotton yarns in basic plain, 1X1 rib, and interlock structures under different relaxed conditions;

ii) the effect of yarn construction (i.e.,a two fold yarn, a two single end yarn and a single end yarn) on the dimensional properties of rib weft knitted structure.

The following experiments were conducted, therefore, to investigate the effect of various relaxation treatments on the dimensional properties of knitted cotton structures and to consider whether the changes of "K" values against various stitch length and relaxation procedures, are similar to those observed in other fabrics knitted from other yarns.

VI.2 Experimental Details

In order to investigate the purposes of this work, five series of fabric were produced of the following basic structures:

a) Interlock structure with 1/34 cotton yarn (17.37 Tex).

b) Plain structure with 2/34 cotton yarn (R34.73 Tex/2).

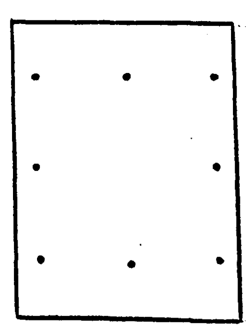
c) 1X1 rib structure with 1/18 cotton yarn (32.8 Tex).

d) 1X1 rib structure with 2/34 cotton yarn (R34.7 Tex/2).

e) 1X1 rib structure with 2X1/34 cotton yarn (2 ends of 17.37 Tex).

Each group was knitted in four different stitch lengths. The range of stitch lengths in each construction and tightness is indicated in Table(6.1) and marked for identification as in the same Table.

A three metre length sample was knitted for each sample of each stitch length, and from each of these, six pieces (of area 40 cm. by 30 cm.) were separated and marked by numbers 1, 2, 3, 4, 5 and 6. At this stage the cut samples consisted of two pieces on top of each other, because the fabrics were knitted in tubular form. In order to prevent the fabric samples from curling during testing, the edges of these samples were overlocked, by using an overlock machine, thus sewing the two samples together. All these sewn samples were placed individually on a flat table, and in the middle of them, a square of 25 cm. by 25 cm. was measured by means of a template and marked by three points in the length and width directions, by a black permanent marker, so that during the wetting and washing these marks still remained (see Figure(6.1)). The average of the three measurements was used in the subsequent calculations.



Figure(6.1)

structure	count of yarn(Tex)	mark of sample	stitch length/cm. measured	unroved	P.D.*
Interlock (single yarn)	17.4	I.1	0.434	0.436	0.46%
		I.2	0.384	0.385	0.26%
		I.3	0.359	0.357	0.55%
		I.4	0.333	0.335	0.60%
Plain (two-fold yarn)	R34.8/2	P.1	0.534	0.541	1.31%
		P.2	0.459	0.463	0.87%
		P.3	0.416	0.411	1.20%
		P.4	0.373	0.379	1.60%
Rib (single yarn)	32.8	R.1.1	0.507	0.509	0.39%
		R.1.2	0.464	0.464	0.00%
		R.1.3	0.415	0.417	0.48%
		R.1.4	0.391	0.394	0.77%
Rib (two-fold yarn)	R34.8/2	R.2.1	0.507	0.505	0.39%
		R.2.2	0.464	0.466	0.43%
		R.2.3	0.415	0.413	0.48%
		R.2.4	0.391	0.392	0.25%
Rib (two ends yarn)	two ends of 17.4	R.3.1	0.507	0.510	0.59%
		R.3.2	0.464	0.468	0.86%
		R.3.3	0.415	0.419	0.95%
		R.3.4	0.391	0.393	0.51%

Table(6.1) The fabrics knitted in this work.

* percentage differences between the measured stitch length by the yarn length counter and the unroved stitch length.

VI.2.1 Control Of sample Quality

In this work,to control the stitch length in the samples, a positive feed device was used in the interlock machine and rib machine, but the single jersey machine was not equipped with a positive feed device, thus, the stitch length was formed in a negative manner.

The measurement of stitch lengths, for all samples, was conducted by HATRA yarn length counter and checked on a HATRA course length tester. The detailed results are given in Appendix 1 and the average stitch length values calculated from the yarn length counter reading and course length tester reading are given in Table(6.1).

In order to obtain the required course length, the positive feed device (in the interlock and rib machines), and the cam setting (in the single jersey machine) were adjusted. The setting of all feeders in the single jersey machine was determined in this way. This was very vital to make sure that the yarn lengths of each course of each particular fabric sample corresponded to the required stitch length. Yarn speed was also measured in each feeder and then recorded (only in the single jersey machine). During knitting the yarn tension in all feeders was recorded, by tension meter, and adjusted to approximately 3 grams.

VI.3 Details Of Relaxation Treatments

It is to be noted that two different groups of samples had to be taken from each of the original samples with the intention of more investigation of various relaxation procedures' effects on the behaviour of the fabric shrinkage.

The first group, which are marked by numbers 1, 2, and 3 (appendices 2 to 21), were relaxed gradually for different time periods under the following treatments respectively:

a) Dry relaxation (D.R.).

b) Wet relaxation (W.R.).

c) Wet relaxation and tumble dry (W.R.+T.D.).

d) Wet relaxation and tumble dry followed by washing machine and tumble dry G(W.M.+T.D.).

The other group, i.e.,the samples numbered 4, 5, and 6 (appendices 22 to 26), were given a direct washing and tumble drying treatment (W.M.+T.D.).

a) Dry Relaxation

The first group of fabrics were left lying on a flat surface for 16 hours and then their dimensions between the marked points, were measured.

b) Static Wet Relaxation

After the dry relaxation, the same fabric samples were immersed in a sink full of water with a wetting agent.

The water temperature was initially 40°C, cooling down to room temperature. After 24 hours, excess water was removed manually from the fabrics and they were allowed to dry on flat smooth surface for 40 hours and then measured dry.

c) Static Wet Relaxation and Tumble Dry

The fabrics previously wet relaxed as (b) were re-wetted out under the same conditions as above for 24 hours. After the manual removal of excess water, they were tumble dried at 70°C for 90 minutes. The samples were again laid on a flat table for 16 hours and then, the distance between the marks re-measured.

d) Washing Machine (Wascator) and Tumble Dry

The above samples were further subjected to a laundering process using a Wascator (Fom 71) type machine. This machine has different programmes which are determined by the use of different punched cards.

In this work the washing programme chosen was HLCC 6P/40 which is a 15 minutes wash cycle, at 40°C temperature, with a regular washing action followed by the following rinse and spin cycles:

2X3 minute	rinses (cold)
1X1 minute	rinse (cold)
1X1 minute	spin
1X2 minute	rinse (cold)
1X2 minute	spin

(HLCC meaning Home Laundering Consultative Council)

After being washed,the samples were taken out of the machine and were tumbled again in a dry state for 60 minutes and were removed and allowed to stand on a flat surface for 20 hours and then measured.

The second group of fabrics were relaxed by washing and tumble drying directly, using the same conditions as specified in (d), i.e.,Wascator washing and tumble drying, after dry relaxation treatment (similar to "a"). The fabrics were then laid flat for 16 hours and re-measured.

VI.4 Measurement Of Fabric Parameters

In order to obtain more accurate results from experiments and calculations of fabric parameters, three similar pieces were chosen from each of the original samples for all the experiments and the figures used were the average of the three samples.

VI.4.1 Courses Per Unit Length (C.P.cm.) And Wales Per Unit Length (W.P.cm.)

The total number of courses and wales were counted for all samples within the marks of the measured square (25 cm. X 25 cm.) before any relaxation, and divided by the appropriate length or width measurement after each relaxation to find the average number of courses and wales per centimetre respectively for various relaxation treatments of different structures, as follows:

$$C.P.cm. = \frac{\text{total number of courses}}{\text{measured length in centimetres}}$$

$$W.P.cm. = \frac{\text{total number of wales}}{\text{measured width in centimetres}}$$

VI.4.2 Stitch Density Per Unit Area (S)

The number of stitches per unit area named stitch density (S), and it was calculated as the product of C.P.cm. and W.P.cm. as follows:

$$S = (C.P.cm.) \cdot (W.P.cm.)$$

VI.4.3 Stitch Length (ℓ)

Throughout this thesis the stitch length is defined as the total length of yarn required to form one loop. This parameter was calculated from the total length of yarn required to produce one course (course length) using the following formula:

$$\ell = \frac{\text{course length}}{\text{total number of needles knitting per course}}$$

VI.4.4 K_c, K_w, K_s, And K_r Values

The numerical values of K_c, K_w, K_s and K_r are constants and will depend on the actual configuration of the knitted loop. The values K_c, K_w and K_s were calculated for each of the samples with different structures at all stages of relaxation by the following formulae:

$$K_c = (\text{C.P.cm.}) \cdot \ell$$
$$K_w = (\text{W.P.cm.}) \cdot \ell$$
$$K_s = (S) \cdot \ell^2$$

The K_r parameter is defined as the proportion of $\frac{K_c}{K_w}$ which may be described as the loop shape factor as it is a measure of the ratio of the wale spacing (width of the loop) to course spacing (length of the loop) and was calculated from the following formula:

$$K_r = \frac{\text{C.P.cm.}}{\text{W.P.cm.}}$$

VI.5 Experimental Results

The measurements of the number of courses and wales per 25 centimetre (the distance between marker points) for the samples, which are listed in Table(6.1), are given before any relaxation treatment in appendix 27. The use of the measured distances between marker points in this manner reduces the problems of measuring and is more accurate than the use of a piece glass.

On the other hand, the width and length of each sample was ascertained at each stage of relaxation, as described under section VI.3, by measuring the distance between the marker points. Both width and length were determined in three different places and the average taken. The numerical results of the first group,i.e.,the pieces of fabrics, which were numbered 1, 2 and 3 are tabulated in appendices 2 to 21, and the second group fabrics measurements are shown in appendices 22 to 26.

CHAPTER VII

ANALYSIS AND DISCUSSION OF RESULTS

VII.1 Discussion Of "K_s" And "K_r" Values

As mentioned in section VI.4 in order to calculate the "K_c", "K_w", "K_s" and "K_r" values from the practical results, it is necessary to obtain the stitch length and the number of courses and wales per centimetre. For this purpose C.P.cm. and W.P.cm. and the inverse of stitch length were derived from previous measurements, and then "K_c", "K_w", "K_s" and "K_r" values were calculated by using the appropriate formula (see section VI.4) for each sample and are shown in Tables (7.1), (7.2), (7.3), (7.4), (7.5) in the different relaxation conditions. A computer program (see Appendix 55) was devised in Basic Language to determine the "K" values from the dimensional and stitch length measurements.

In order to ascertain more easily the effect of each stitch length and relaxation condition on the "K_s" and "K_r" values of samples, it was decided to plot these parameters graphically against the stitch length in different relaxation states and also against the relaxation state for each stitch length. Each structure was plotted separately in this manner and a similar set of graphs was obtained for each relaxation state. Figures (7.1) to (7.10) indicate the effect on "K_s" values and Figures (7.11) to (7.20) the effect on "K_r".

VII.1.1 "K_s" Values

From Figures (7.1) to (7.10) the following facts may be noted:

i) As shown in Figures (7.1) to (7.5), a considerable difference in "K_s" values, as the result of gradual relaxation treatment, was observed from the measurements of the individual structures. The "K_s" value increases with increased relaxation but this increase is mainly during the wet relaxation treatment, after this state the change is slight and after washing and tumble drying no further dimensional change occurs. The "K_s" values for each structure at all stages of relaxation treatments are shown in Table(7.6).

ii) As observed in the same graphs, the fabrics relax to the same dimensions after machine washing and tumble drying whether this is done immediately on the sample after knitting or in gradual stages of relaxation (i.e., there is no significant difference between "K_s" values in (W.M.+T.D.) treatment and G(W.M.+T.D.) treatment).

This feature has been confirmed by a statistical consideration which was devised in a computer program (see Appendix 56) and the results were recorded in Table(7.7). An exception can be observed in the case of rib fabrics which were knitted with two-fold yarns.

iii) Examination of these graphs indicates that whereas for the rib and plain structures the "K_s" values after washing and tumble dry do not vary with stitch length of the sample, in the case of the interlock structure, the

(D.R.)

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.436	8.61	14.02	3.73	6.08	22.73	0.61	2.29
I.2	0.385	9.72	13.64	3.73	5.23	19.54	0.71	2.60
I.3	0.357	10.92	13.40	3.92	4.81	18.85	0.81	2.80
I.4	0.335	11.87	13.64	3.95	4.54	17.95	0.87	2.99
P.1	0.541	7.63	8.64	4.07	4.61	18.79	0.88	1.85
P.2	0.463	9.60	8.88	4.40	4.07	17.96	1.08	2.16
P.3	0.411	11.22	9.12	4.66	3.79	17.70	1.23	2.43
P.4	0.379	14.92	9.18	5.56	3.42	19.05	1.62	2.64
R.1.1	0.509	7.73	7.20	3.91	3.65	14.30	1.07	1.96
R.1.2	0.464	8.88	7.06	4.12	3.27	13.49	1.25	2.15
R.1.3	0.417	10.44	7.07	4.33	2.93	12.71	1.47	2.40
R.1.4	0.394	11.65	6.96	4.55	2.72	12.39	1.67	2.54
R.2.1	0.505	7.78	6.30	3.94	3.19	12.59	1.23	1.98
R.2.2	0.466	9.00	6.22	4.17	2.88	12.05	1.44	2.15
R.2.3	0.413	10.58	6.73	4.39	2.79	12.26	1.57	2.42
R.2.4	0.392	11.81	6.77	4.61	2.64	12.22	1.74	2.55
R.3.1	0.510	7.83	7.54	3.96	3.82	15.17	1.03	1.96
R.3.2	0.468	9.35	7.36	4.33	3.41	14.81	1.27	2.14
R.3.3	0.419	10.73	7.19	4.45	2.98	13.28	1.49	2.39
R.3.4	0.393	12.41	6.84	4.85	2.67	12.97	1.81	2.54

Table(7.1) The dimensional parameters of the fabrics after dry relaxätion.

(W.R.)

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.436	11.34	12.41	4.92	5.38	26.50	0.91	2.29
I.2	0.385	12.67	13.05	4.86	5.01	24.38	0.97	2.60
I.3	0.357	13.67	13.35	4.90	4.79	23.52	1.02	2.80
I.3	0.335	14.80	13.98	4.92	4.65	22.94	1.05	2.99
P.1	0.541	9.46	7.88	5.05	4.20	21.25	1.20	1.85
P.2	0.463	11.43	8.88	5.24	4.07	21.38	1.28	2.16
P.3	0.411	13.11	9.70	5.45	4.03	22.00	1.35	2.43
P.4	0.379	15.61	10.63	5.82	3.96	23.08	1.46	2.64
R.1.1	0.509	9.90	6.47	5.01	3.28	16.46	1.53	1.96
R.1.2	0.464	10.94	6.90	5.07	3.20	16.25	1.58	2.15
R.1.3	0.417	12.32	7.55	5.11	3.13	16.01	1.63	2.40
R.1.4	0.394	13.32	7.74	5.20	3.02	15.76	1.72	2.54
R.2.1	0.505	9.65	6.27	4.89	3.17	15.55	1.53	1.98
R.2.2	0.466	10.72	6.49	4.97	3.01	14.97	1.65	2.15
R.2.3	0.413	12.49	7.22	5.18	2.99	15.53	1.72	2.47
R.2.4	0.392	13.44	7.56	5.25	2.95	15.53	1.77	2.55
R.3.1	0.510	9.63	6.80	4.88	3.44	16.83	1.41	1.96
R.3.2	0.468	11.15	7.27	5.17	3.37	17.45	1.53	2.14
R.3.3	0.419	12.79	7.68	5.30	3.18	16.91	1.66	2.39
R.3.4	0.393	14.11	7.68	5.51	3.00	16.56	1.83	2.54

Table(7.2) The dimensional parameters of the fabrics after wet relaxation.

(W.R.+T.D.)

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.436	11.99	14.44	5.20	6.26	32.61	0.83	2.29
I.2	0.385	13.52	14.85	5.19	5.70	29.60	0.91	2.60
I.3	0.357	14.55	14.71	5.22	5.28	27.58	0.98	2.80
I.4	0.335	15.75	14.96	5.24	4.98	26.12	1.05	2.99
P.1	0.541	10.11	8.37	5.39	4.46	24.13	1.20	1.85
P.2	0.463	12.00	9.29	5.50	4.26	23.48	1.29	2.16
P.3	0.411	13.68	10.13	5.69	4.21	23.98	1.35	2.43
P.4	0.379	16.01	10.99	5.97	4.09	24.47	1.45	2.64
R.1.1	0.509	10.67	7.06	5.40	3.57	19.36	1.51	1.96
R.1.2	0.464	11.63	7.52	5.39	3.48	18.82	1.54	2.15
R.1.3	0.417	13.00	8.15	5.39	3.38	18.24	1.59	2.40
R.1.4	0.394	13.96	8.37	5.45	3.27	17.86	1.66	2.54
R.2.1	0.505	10.21	6.70	5.17	3.39	17.58	1.52	1.98
R.2.2	0.466	11.37	6.98	5.27	3.23	17.08	1.62	2.15
R.2.3	0.413	12.85	7.72	5.33	3.20	17.08	1.66	2.47
R.2.4	0.392	13.82	8.02	5.40	3.13	16.94	1.72	2.55
R.3.1	0.510	10.57	7.19	5.35	3.64	19.53	1.47	1.96
R.3.2	0.468	11.84	7.67	5.49	3.55	19.55	1.54	2.14
R.3.3	0.419	13.30	8.18	5.51	3.39	18.73	1.62	2.39
R.3.4	0.393	14.37	8.25	5.61	3.22	18.12	1.74	2.54

Table(7.3) The dimensional parameters of the fabrics after wet relaxation and tumble dry.

G(W.M.+T.D.)

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.436	12.27	13.14	5.32	5.70	30.36	0.93	2.29
I.2	0.385	13.83	14.16	5.31	5.43	28.87	0.97	2.60
I.3	0.357	14.95	14.21	5.36	5.10	27.37	1.05	2.80
I.4	0.335	16.09	14.64	5.35	4.87	26.12	1.09	2.99
P.1	0.541	10.22	8.24	5.45	4.40	24.01	1.24	1.85
P.2	0.463	12.06	9.21	5.53	4.22	23.40	1.30	2.16
P.3	0.411	13.75	10.00	5.72	4.16	23.79	1.37	2.43
P.4	0.379	15.94	10.99	5.94	4.09	24.37	1.45	2.64
R.1.1	0.509	10.73	6.74	5.44	3.41	18.58	1.59	1.96
R.1.2	0.464	11.76	7.36	5.45	3.41	18.63	1.59	2.15
R.1.3	0.417	13.20	8.15	5.47	3.38	18.52	1.61	2.40
R.1.4	0.394	14.17	8.41	5.54	3.28	18.21	1.68	2.54
R.2.1	0.505	10.49	6.67	5.31	3.38	17.98	1.57	1.98
R.2.2	0.466	11.61	7.08	5.38	3.28	17.69	1.63	2.15
R.2.3	0.413	13.11	7.90	5.44	3.27	17.83	1.65	2.42
R.2.4	0.392	14.09	8.26	5.50	3.22	17.79	1.70	2.55
R.3.1	0.510	10.87	7.03	5.51	3.56	19.64	1.54	1.96
R.3.2	0.468	12.15	7.67	5.63	3.55	20.06	1.58	2.14
R.3.3	0.419	13.64	8.29	5.66	3.44	19.47	1.64	2.39
R.3.4	0.393	14.71	8.50	5.75	3.32	19.11	1.73	2.54

Table(7.4) The dimensional parameters of the fabrics after washing and tumble drying.

(W.M.+T.D.)

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.436	12.13	14.89	5.26	6.46	34.02	0.81	2.29
I.2	0.385	13.67	15.46	5.24	5.93	31.16	0.88	2.60
I.3	0.357	14.86	15.47	5.33	5.55	29.62	0.96	2.80
I.4	0.335	16.00	15.36	5.32	5.11	27.25	1.04	2.99
P.1	0.541	10.05	8.50	5.36	4.53	24.35	1.18	1.85
P.2	0.463	12.37	9.14	5.67	4.19	23.81	1.35	2.16
P.3	0.411	13.55	10.09	5.63	4.19	23.66	1.34	2.43
P.4	0.379	15.88	11.09	5.92	4.13	24.50	1.43	2.64
R.1.1	0.509	10.61	7.03	5.37	3.56	19.17	1.50	1.96
R.1.2	0.464	11.69	7.59	5.42	3.52	19.10	1.54	2.15
R.1.3	0.417	13.00	8.26	5.39	3.42	18.49	1.57	2.40
R.1.4	0.394	13.83	8.58	5.40	3.35	18.14	1.61	2.54
R.2.1	0.505	10.21	6.59	5.17	3.34	17.29	1.54	1.98
R.2.2	0.466	11.20	7.11	5.19	3.29	17.14	1.57	2.15
R.2.3	0.413	12.61	7.68	5.23	3.18	16.67	1.64	2.42
R.2.4	0.392	13.76	8.10	5.38	3.16	17.03	1.69	2.55
R.3.1	0.510	10.52	7.16	5.33	3.63	19.36	1.46	1.96
R.3.2	0.468	11.72	7.73	5.43	3.58	19.50	1.51	2.14
R.3.3	0.419	13.23	8.33	5.49	3.45	18.98	1.58	2.39
R.3.4	0.393	14.37	8.50	5.61	3.32	18.67	1.69	2.54

Table(7.5) The dimensional parameters of the fabrics after washing and tumble drying immediately after dry relaxation.

Relaxation	Interlock	Plain	Rib (single)	Rib (2-fold)	Rib (2-ends)
(D.R.)	20.3±2.4	18.4±0.7	13.3±1.0	12.3±0.3	14.1±1.1
(W.R.)	24.7±1.8	22.2±0.9	16.1±0.3	15.3±0.3	17.0±0.4
(W.R.+T.D.)	29.4±3.2	24.0±0.5	18.6±0.7	17.3±0.3	18.8±0.7
G(W.M.+T.D.)	28.2±2.1	23.9±0.5	18.4±0.2	17.8±0.1	19.6±0.5
(W.M.+T.D.)	30.6±3.4	24.1±0.4	18.7±0.5	17.0±0.3	19.1±0.4

Table(7.6) "K_s" values for all structures at different relaxation states.

Structure	Mean K_{s1}*	Mean K_{s2}**	V_1	V_2	S	t-test	Sig.
Interlock	30.55	28.16	6.707	3.002	2.203	2.650	5%
Plain	24.08	23.92	0.169	0.187	0.422	0.944	N.S.***
Rib(single)	18.71	18.48	0.199	0.061	0.361	1.575	N.S.
Rib(2-fold)	17.04	17.83	0.078	0.024	0.226	8.570	1%
Rib(2-ends)	19.17	19.56	0.107	0.138	0.350	2.729	5%

Table(7.7) Comparison of "K_s" values at (W.M.+T.D.) and G(W.M.+T.D.) states.

* Value of "K_s" after (W.M.+T.D.).

** Value of "K_s" after G(W.M.+T.D.).

*** Non-significant.

"K_s" values of the samples even after this degree of relaxation are significantly different. The effect is seen more clearly in Figures (7.6) to (7.10) where the "K_s" value has been plotted against stitch length for all the different structures. Whereas in the case of all the plain and rib structures, after washing and tumbling, the appropriate line is almost horizontal, indicating that the "K_s" value is not affected by the stitch length of the sample, in the case of the interlock there is a very marked slope, indicating that the "K_s" value increases with increase in stitch length, even after this severe relaxation process.

iv) From the above observations it is clear that whereas in the case of the interlock structures the slope of the "K_s" versus stitch length relationship is significantly different from zero, for all stages of relaxation, for the other structures this slope decreases with relaxation, giving very low values after washing and tumbling.

Relationships previously suggested,by Munden[10] and others[30, 39],that when relaxed the "K_s" value is a constant and independent of stitch length.

To see if this is the case for the fabrics presently under consideration, it is important to see if the slope of the "K_s" versus stitch length curve is significantly different from zero. If not then these findings by previous workers, apply for the rib and plain cotton fabrics.

In order to consider the form of the graphs of "K_s" against stitch length for all the structures in different relaxation, a statistical method was employed. In this method the data for each graph of Figures (7.6) to (7.10) consists of four readings for each of these observations, there are nine, six or three variable "y" (i.e., "K_s" value) for each of the values of "x" (i.e., stitch length). Thus, the application of the F-test testing for a significant slope will be as follows[57]:

$$\text{F-test} = \frac{n.r.(r - 1).\hat{b}^2.\sum(x_i - \overline{x})^2}{\sum\sum(y_{ij} - \overline{y}_i)^2} \qquad (1)$$

where n= the number of mean values

r= the total number of readings for a group

b= slope

x_i= the "x" of mean

$\overline{y}_i$= the "y" of mean

y_{ij}= the "y" of all readings

n.(r - 1)= degree of freedom.

The slopes of the best fit lines and their formulae relating "K_s" with stitch length for all structures have been found by a computer program[58] and the detailed results were given in appendices 28 to 32.

From the above information the F-test values were found for all structures individually by a set of computer programs which were devised in Basic Language and shown in appendices 57 to 60. The results have been summarized in

Table(7.8). Then the statistical significance at the 5% and 1% levels were found for all fabrics by comparison with the F-test table with the appropriate degree of freedom. The results are recorded in Table(7.9).

Structure / treatment	Interlock	Plain	Rib (single)	Rib (2-fold)	Rib (2-ends)
(D.R.)	3443.383	0.736	5047.368	193.606	4755.175
(W.R.)	125.812	89.923	7.421	0.691	2.593
(W.R.+T.D)	1366.032	5.063	104.760	23.948	122.153
G(W.M+T.D)	275.307	4.559	3.714	0.858	17.346

Table(7.8) The values of F-test for all fabrics.

Structure / treatment	Interlock	Plain	Rib (single)	Rib (2-fold)	Rib (2-ends)
(D.R.)	1%	N.S.*	1%	1%	1%
(W.R.)	1%	1%	5%	N.S.	N.S.
(W.R.+T.D)	1%	5%	1%	1%	1%
G(W.M+T.D)	1%	5%	N.S.	N.S.	1%

Table(7.9) Statistical significance of relating "K_s" with stitch length in comparison with horizontal line for all fabrics.

* non-significant

It can be observed from Table(7.9):

a) in the case of interlock fabrics, the variation of "K_s" values with stitch length in all states of relaxation , was significant at 1% level;

b) in the case of plain fabrics this variation in all states of relaxation is non-significant or significant only at 5% level, except after wet relaxation;

c) in the case of rib fabrics in the dry relaxed state the "K_s" value varies with stitch length at the 1% level but after further relaxations the variation was non-significant except after wet relaxation and tumble drying.

Thus in general terms the statistical analysis confirms that with increased relaxation in the case of plain and rib fabrics the "K_s" values become independent of stitch length, whereas in the case of interlock the "K_s" value remains highly significantly affected by the knitted stitch length.

The two anomalous statistical figures (i.e., rib after wet relaxation and tumble dried and plain after wet relaxation) justify further consideration.

In both these cases, although statistically the slopes are deemed to be affected by stitch length, examination of the "K_s" values for these fabrics in these states of relaxation indicates that the range in "K_s" value from tightest to slackest fabrics is very small, in fact sufficiently small to be within the experimental limits of the measurements themselves, e.g., (see Table 7.6), plain wet relaxed "K_s" values range from 23.1 – 21.3,

rib wet and tumble dried "K_s" values range from:

for fabrics knitted with single yarn 19.3 – 17.9;

for fabrics knitted with two-fold yarn 17.6 – 17.0;

for fabrics knitted with two-ends yarn 19.5 – 18.1.

The reason why these results have given on apparently significant effect is the very limited number of readings taken on each sample, and the small range of the "K_s" values calculated at each stitch length. This is to be contrasted with the interlock values with the following range in "K_s" values, which is much greater than the experimental limits of the measurements:

dry relaxed "K_s" values range from 22.7 – 17.9;

wet relaxed "K_s" values range from 26.5 – 22.9;

wet and tumble dried "K_s" values range from 32.6 – 26.2;

washing and tumble dried values range from 30.3 – 26.1.

Hence, it can be concluded that, in all states of relaxation , the "K_s" values for the rib and plain fabrics are almost constant and there is no indication that they vary with stitch length. In the case of interlock structure the "K_s" value varies with stitch length (increasing in value with increase in stitch length) and this effect becomes more marked with increase in severity of the relaxation process. In the case of the plain and rib fabrics the constancy of "K_s" with stitch length improves with increase in relaxation as has been mentioned by many previous workers.

v) As observed in the Figures(7.6) to (7.10), the "K_s" value of rib fabrics which were made with two-fold yarns is lower than for the rib fabrics made with single and two-ends yarns. This fact may be attributed to the behaviour of single and two-fold yarn shrinkage or to the formation of the loops which are knitted with these yarns. This phenomenon will be considered later in more detail.

vi) It can be observed from the results of this work (see Table 7.6),and contrary to Poole and Brown's[44] conclusions for cotton rib fabrics, that the "K_s" values for 1X1 rib and interlock cotton fabrics are considerably higher after a complete relaxation treatment (i.e., after washing and tumble drying treatment), than those found for wool fabrics by previous workers (see Table(3.3), Table(7.10a) and Table(7.10b)).

In the case of the plain fabrics (see Table 7.11), the difference in "K_s" values are not so different in the case of cotton and wool. These points will be discussed in detail in chapters VIII and IX.

SCSL (cm.)	U_s	U_c	U_w	U_r
1.448±0.015	198.9±8.6	20.49±0.44	9.70±0.32	2.11±0.07
1.641±0.020	200.8±10.	20.46±0.41	9.81±0.34	2.09±0.05
1.768±0.028	201.6±15.	20.49±0.78	9.84±0.49	2.09±0.10

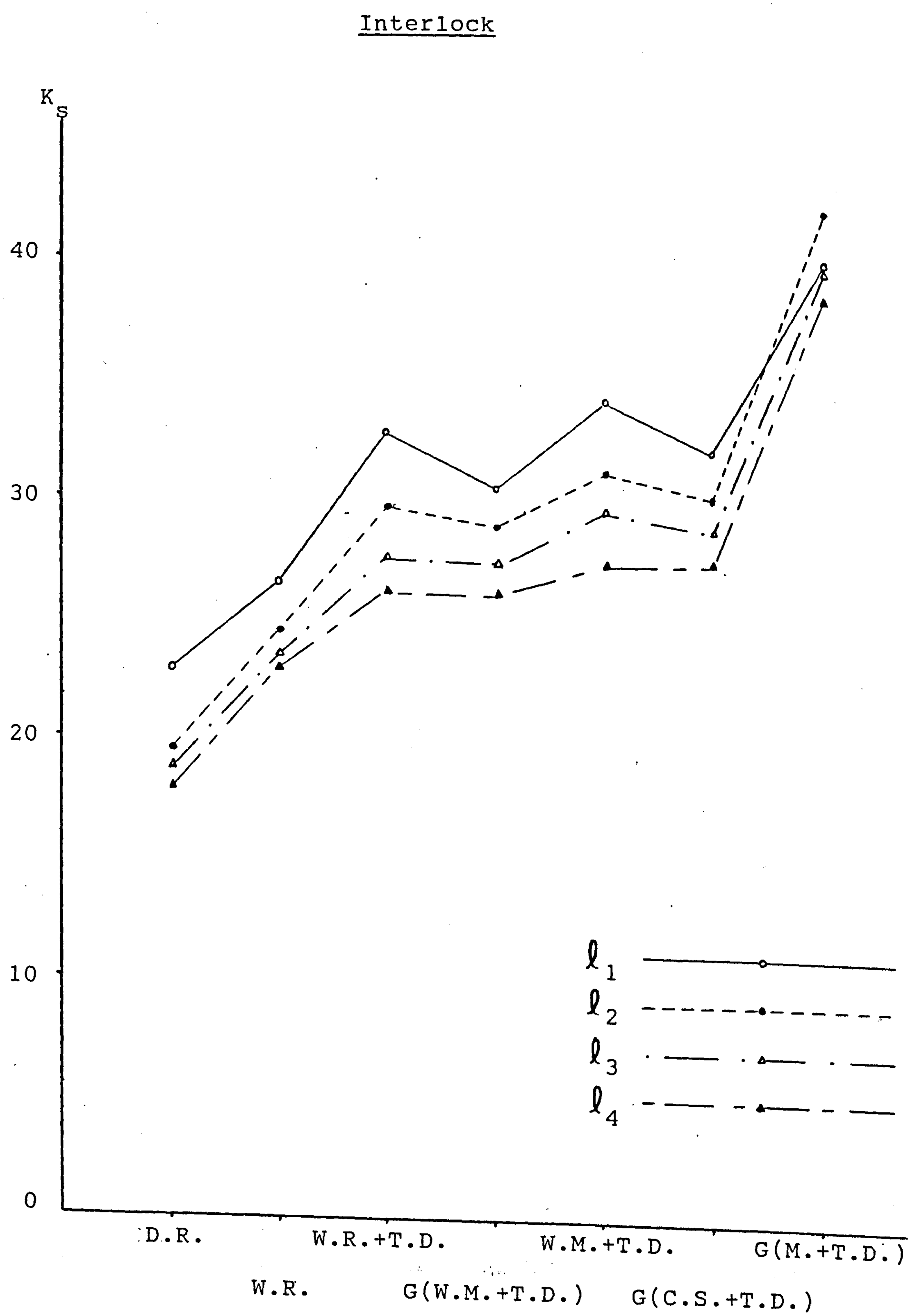
Table(7.10a) Average "U" values for wool interlock structures at various structural-cell stitch lengths in a fully relaxed[59] state.

Stitch length	K_s	K_c	K_w	K_r
0.362±0.04	24.9±1.1	5.12±0.11	4.85±0.16	1.05±0.03
0.410±0.05	25.1±1.2	5.11±0.10	4.90±0.17	1.04±0.02
0.442±0.07	25.2±1.8	5.12±0.20	4.92±0.24	1.04±0.05

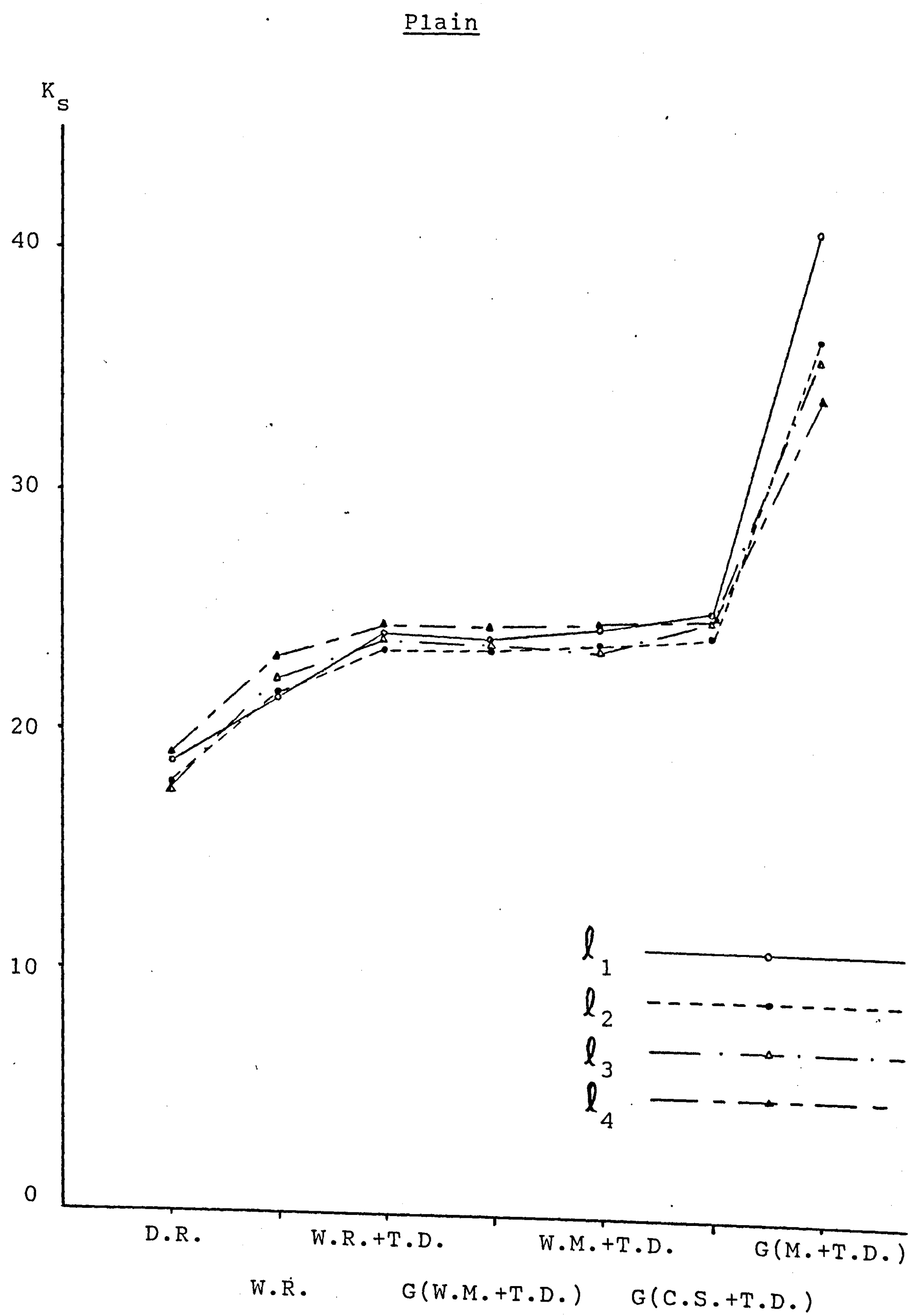
Table(7.10b) Recalculated "K" values for wool interlock structures at various stitch lengths in a fully relaxed state.

Stitch length	K_s	K_c	K_w	K_r
0.141±0.001	23.7±1.0	5.66±0.14	4.18±0.09	1.35±0.02
0.164±0.001	23.5±1.4	5.54±0.20	4.23±0.10	1.31±0.03
0.188±0.001	23.4±1.2	5.53±0.19	4.23±0.11	1.30±0.04

Table(7.11) Average "K" values for wool plain knitted fabrics at various stitch lengths in a fully relaxed[39] state.

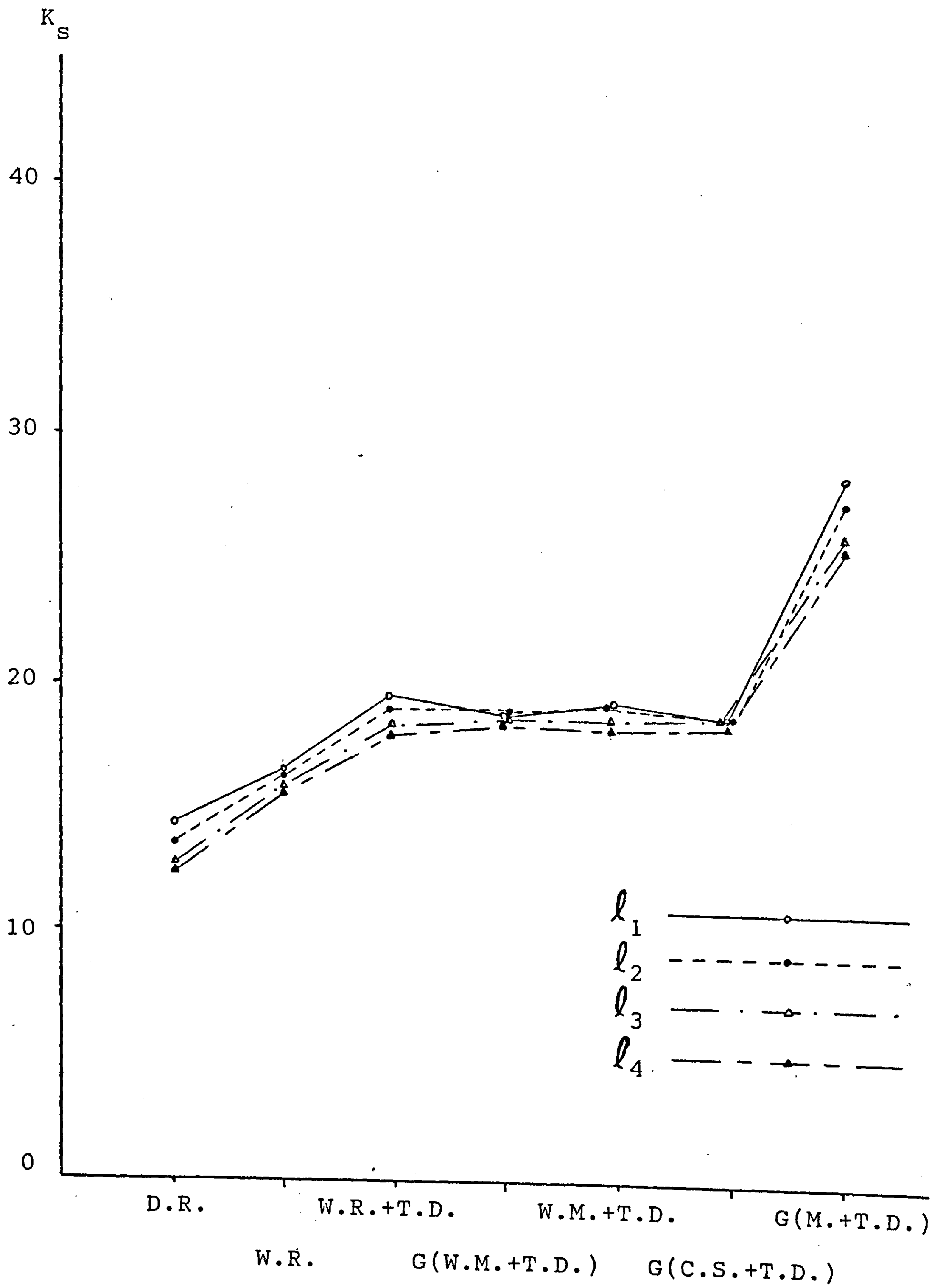


Figure(7.1) "K_s" values versus different relaxation treatments.



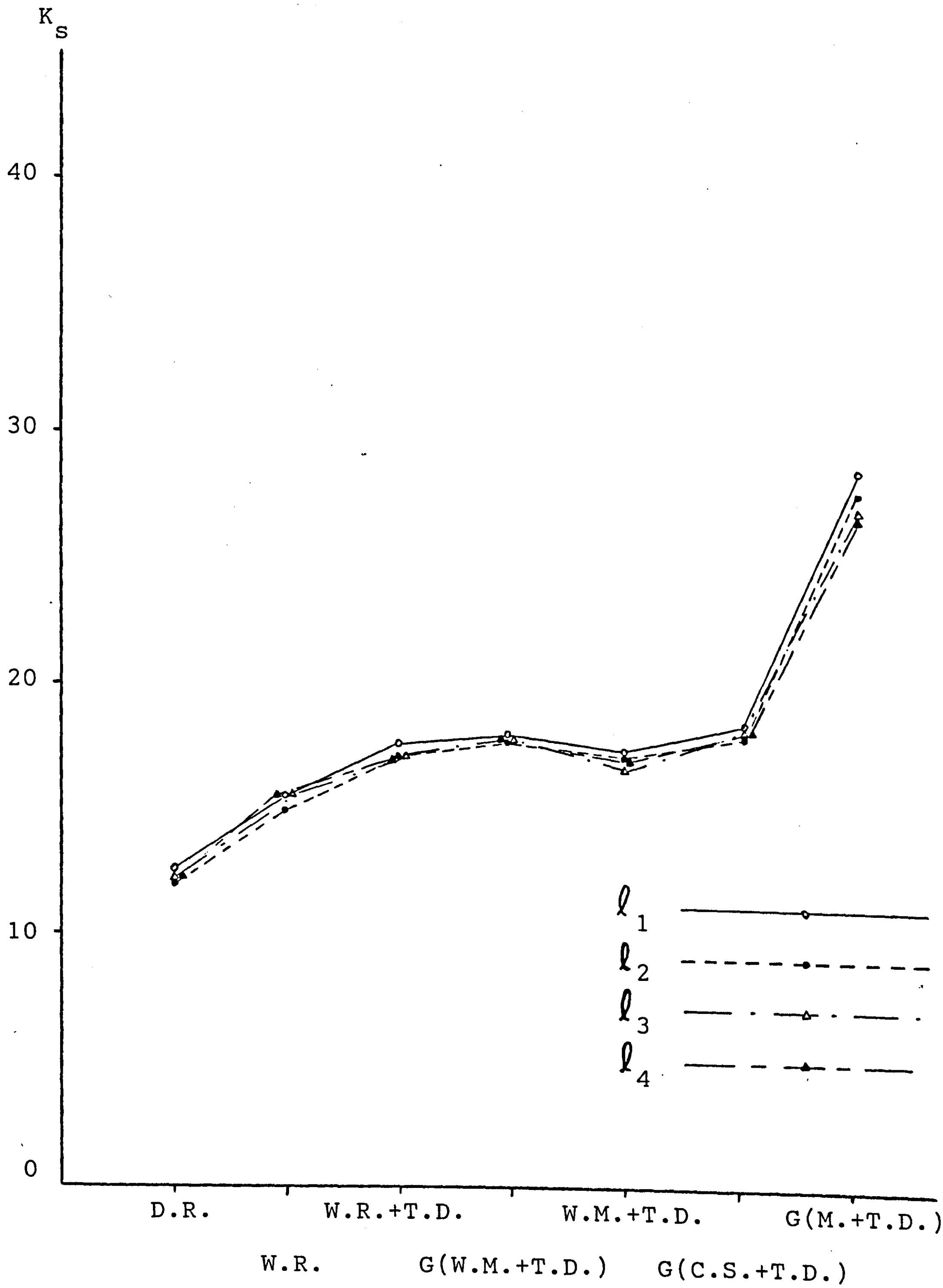
Figure(7.2) "K_s" values versus different relaxation treatments.

Rib (single yarn)



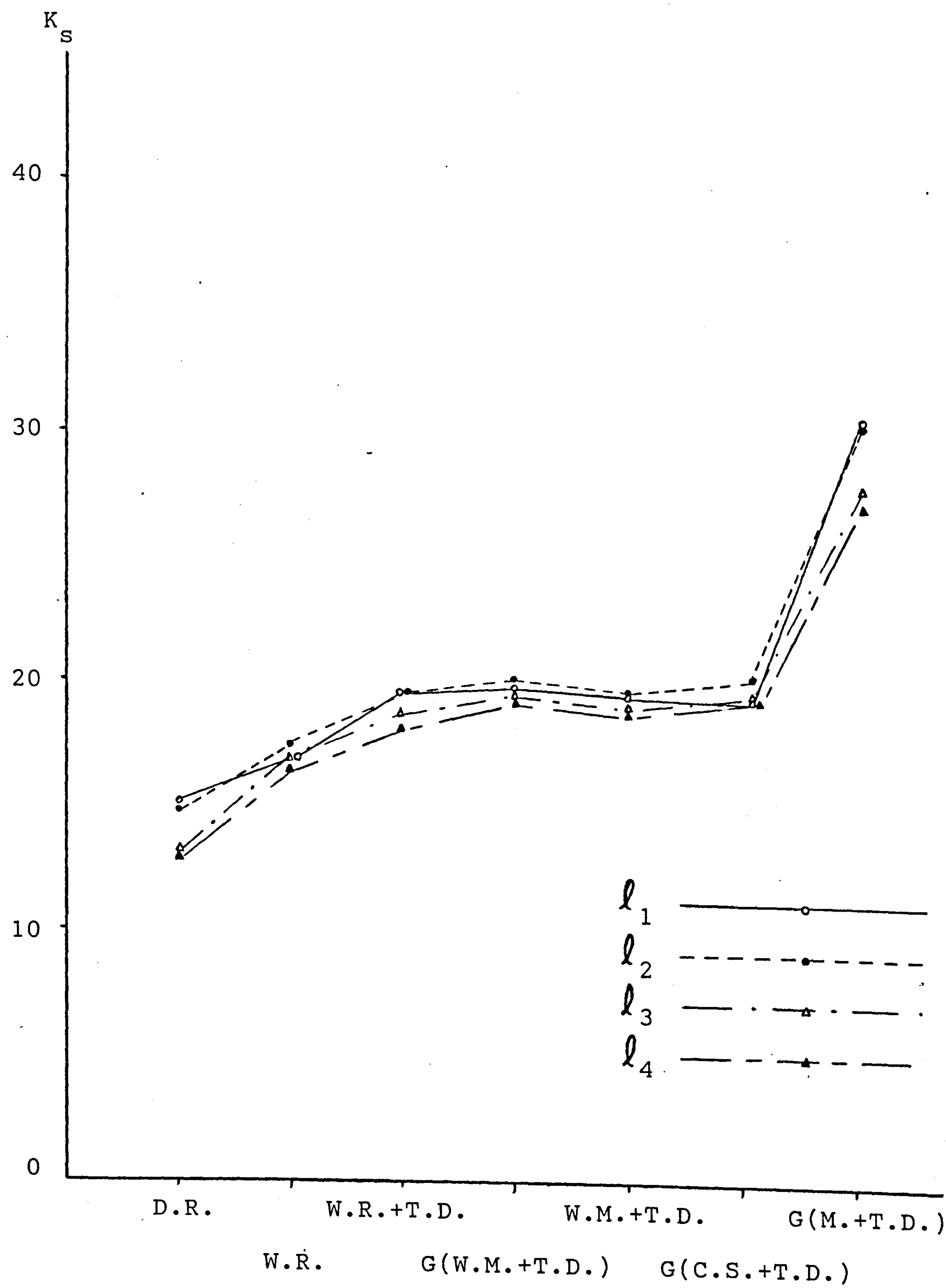
Figure(7.3) "K_s" values versus different relaxation treatments.

Rib (two-fold yarn)

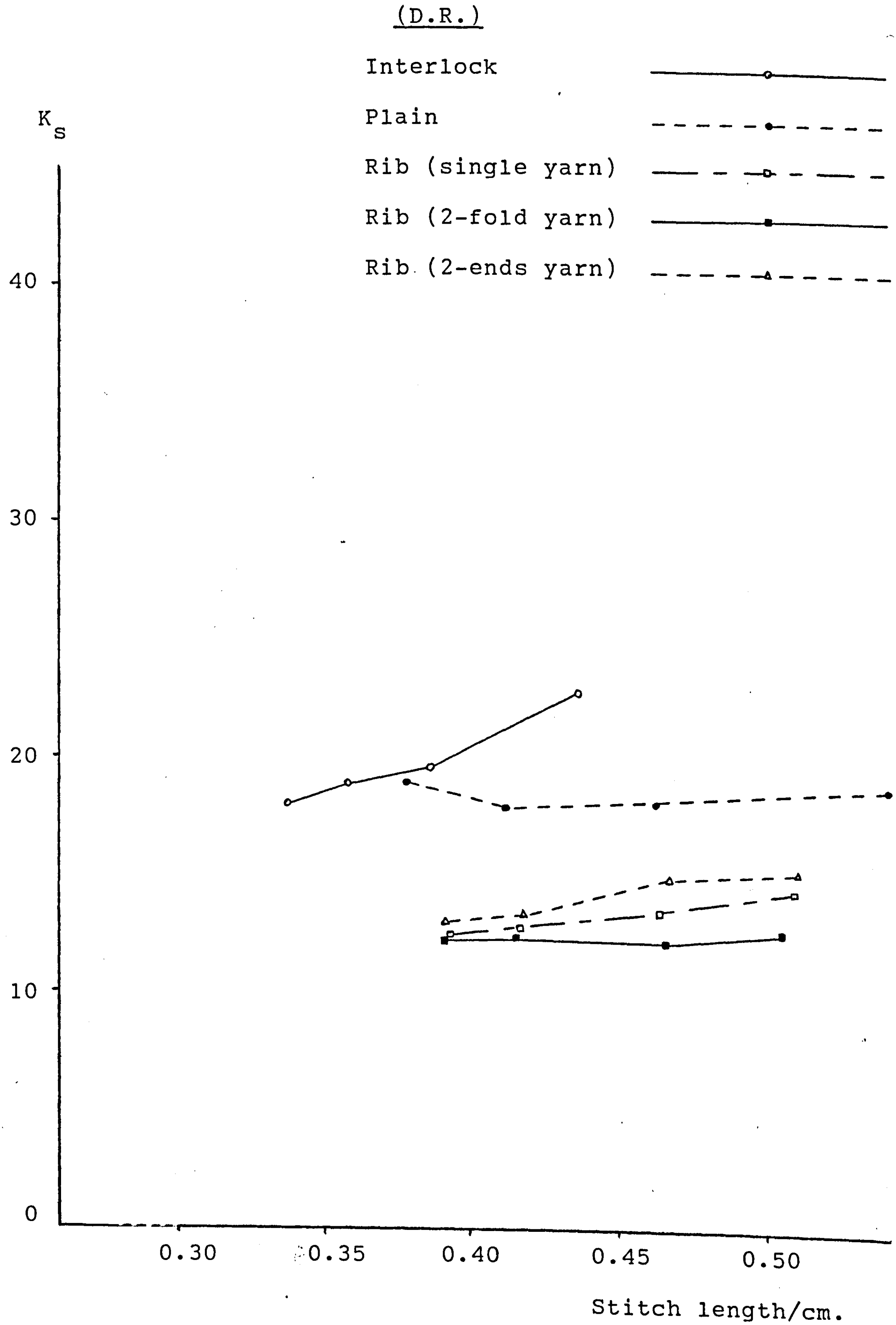


Figure(7.4) "K_s" values versus different relaxation treatments.

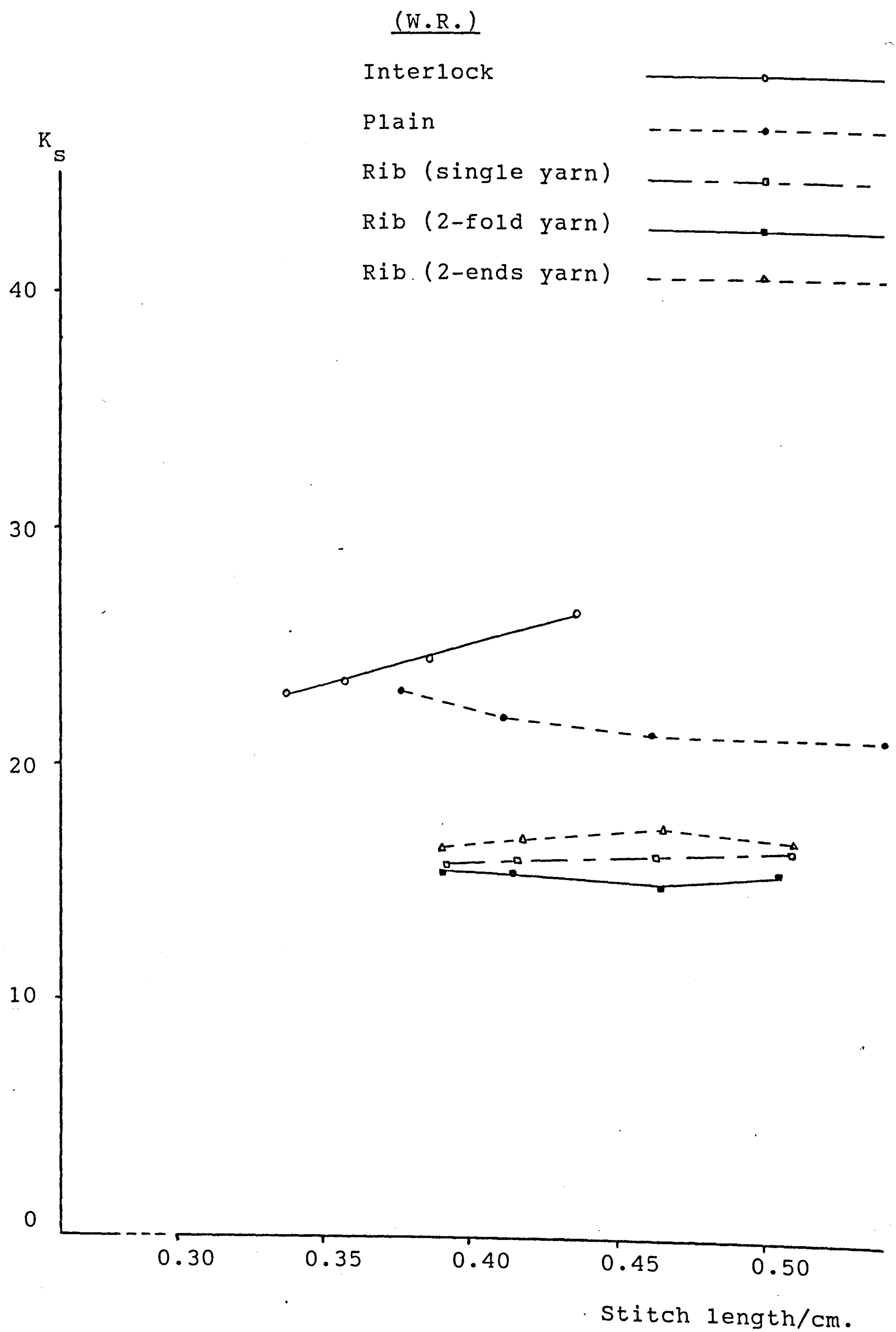
Rib (two-ends yarn)



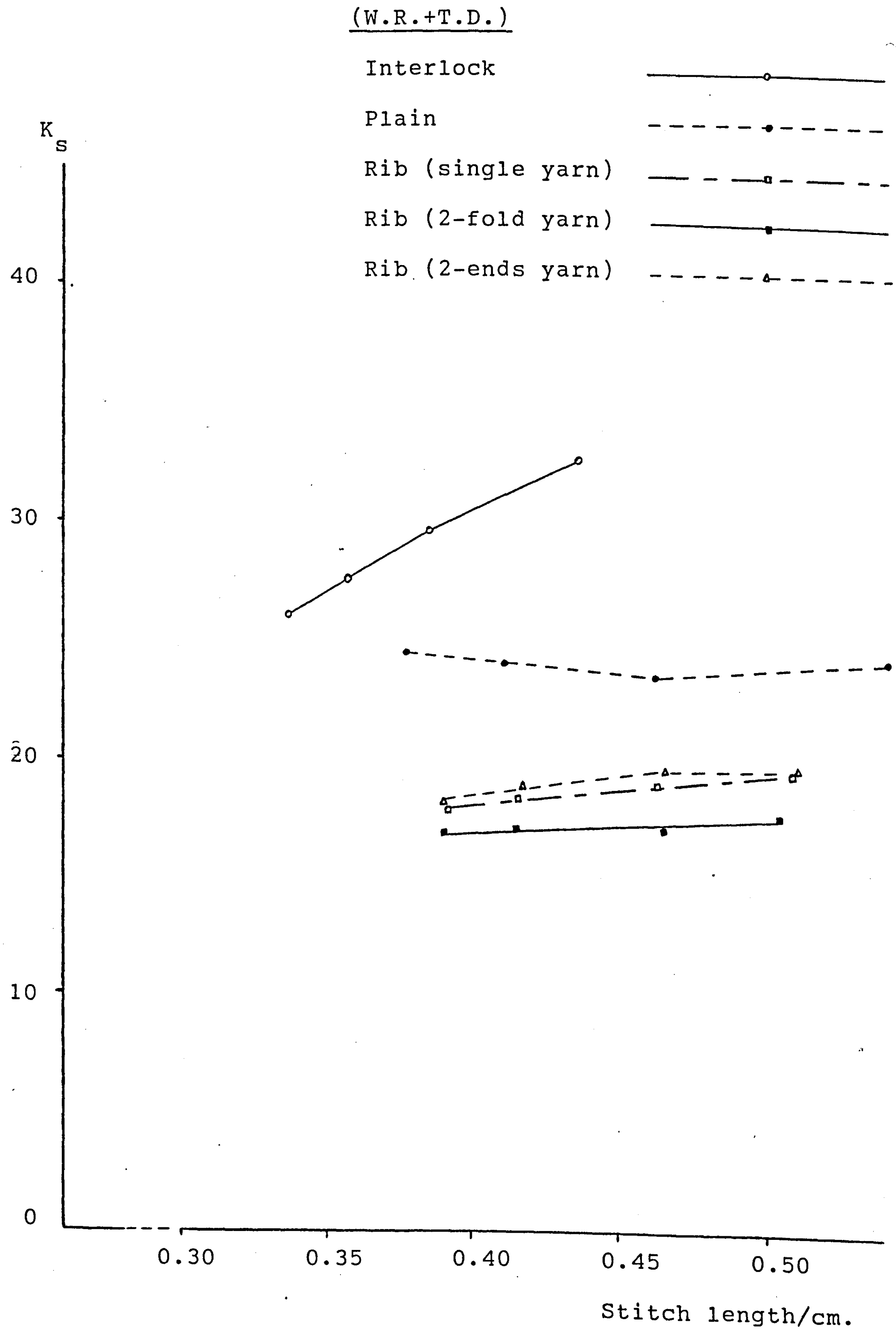
Figure(7.5) "K_s" values versus different relaxation treatments.



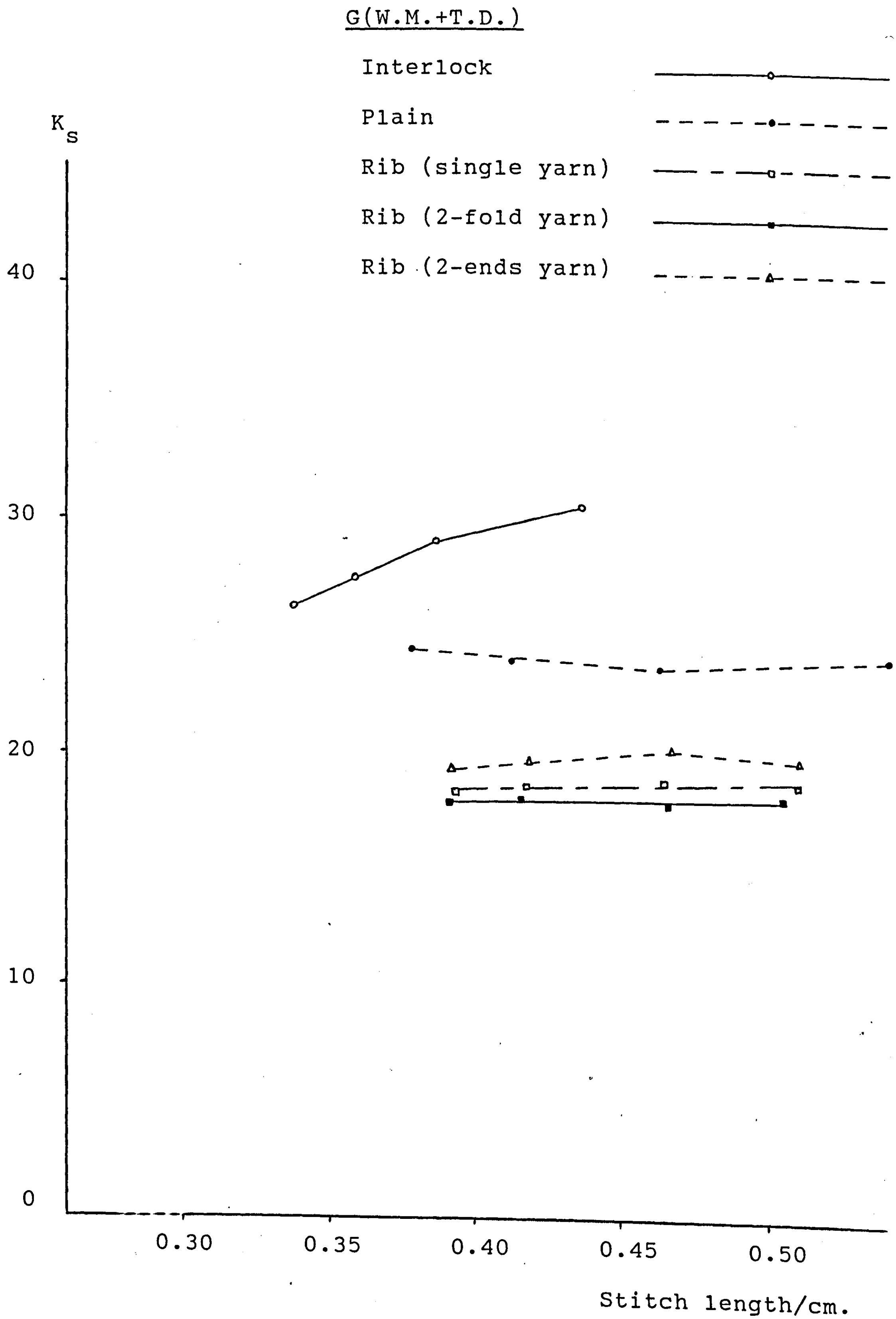
Figure(7.6) "K_s" values versus stitch length.



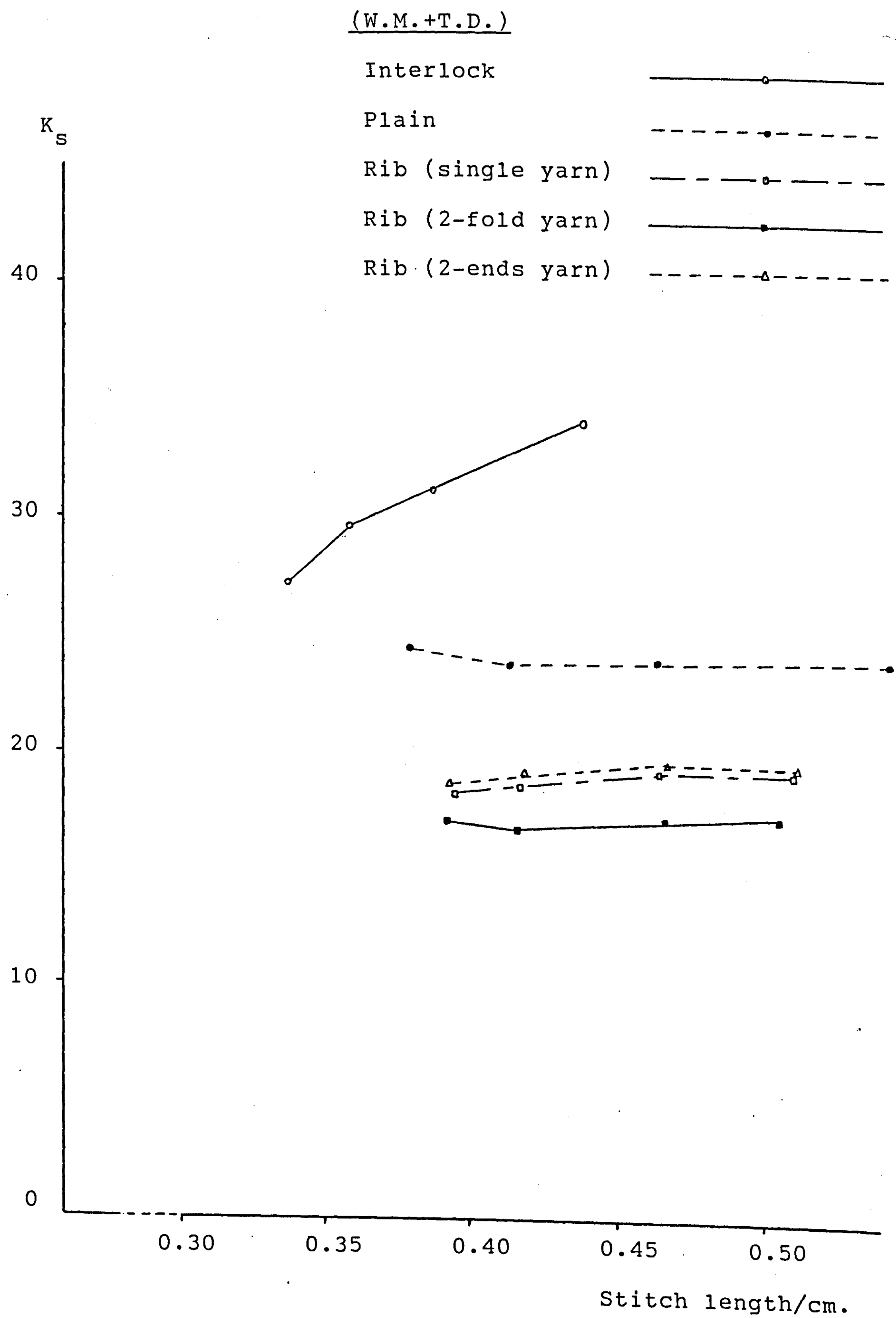
Figure(7.7) "K_s" values versus stitch length.



Figure(7.8) "K_s" values versus stitch length.



Figure(7.9) "K_s" values versus stitch length.



Figure(7.10) "K_s" values versus stitch length.

VII.1.2 "K_r" Values

VII.1.2.1 The "K_r" Values For The Different Structures And The Effect Of Relaxation Treatment

Whereas the "K_s" values are an indication of the area occupied by the loops in the fabric plane, the shape of the loop is best examined by consideration of the "K_r" value $\left(\frac{\text{courses per unit length}}{\text{wales per unit length}}\right)$.

In considering the Figures (7.11) to (7.15), which show the relationship between the "K_r" values against the relaxation treatments for each quality of structure, it was noticed that:

i) After wet relaxation;

a) the "K_r" values increased considerably,

b) there were greater change in "K_r" values for the slacker fabrics than the tighter fabrics. This is due to the fact that the slacker fabrics were much more distorted on the machine than the tighter ones, as is evidenced by the fact that in the dry relaxed state, there is a much greater spread of "K_r" values than after any subsequent relaxation treatment.

ii) After subsequent relaxation treatments, the "K_r" values decreased slightly during further relaxation, this change being small in comparison with the change on wet relaxation.

From Table(7.4), the average "K_r" values, in the washed and tumble dried state, are recorded in Table(7.12) for each of the structures.

Structure	K_r value
interlock	1.01 ± 0.08
plain	1.34 ± 0.10
rib (single yarn)	1.63 ± 0.04
rib (two-fold yarn)	1.63 ± 0.06
rib (two-ends yarn)	1.63 ± 0.09

Table(7.12) The average "K_r" value for different structures after washing and tumble drying treatments, G(W.M.+T.D.).

These values are very similar to those which were obtained by previous workers[60, 59, 39] for wool knitted fabrics (see Table(7.10b), Table(7.11) and Table(3.3)).

VII.1.2.2 The Effect Of Stitch Length On "K_r" Values

The effect of stitch length on "K_r" values is illustrated in Figures (7.16) to (7.20) where the value of "K_r" for the structures is plotted against stitch length. From these graphs the following points may be noted:

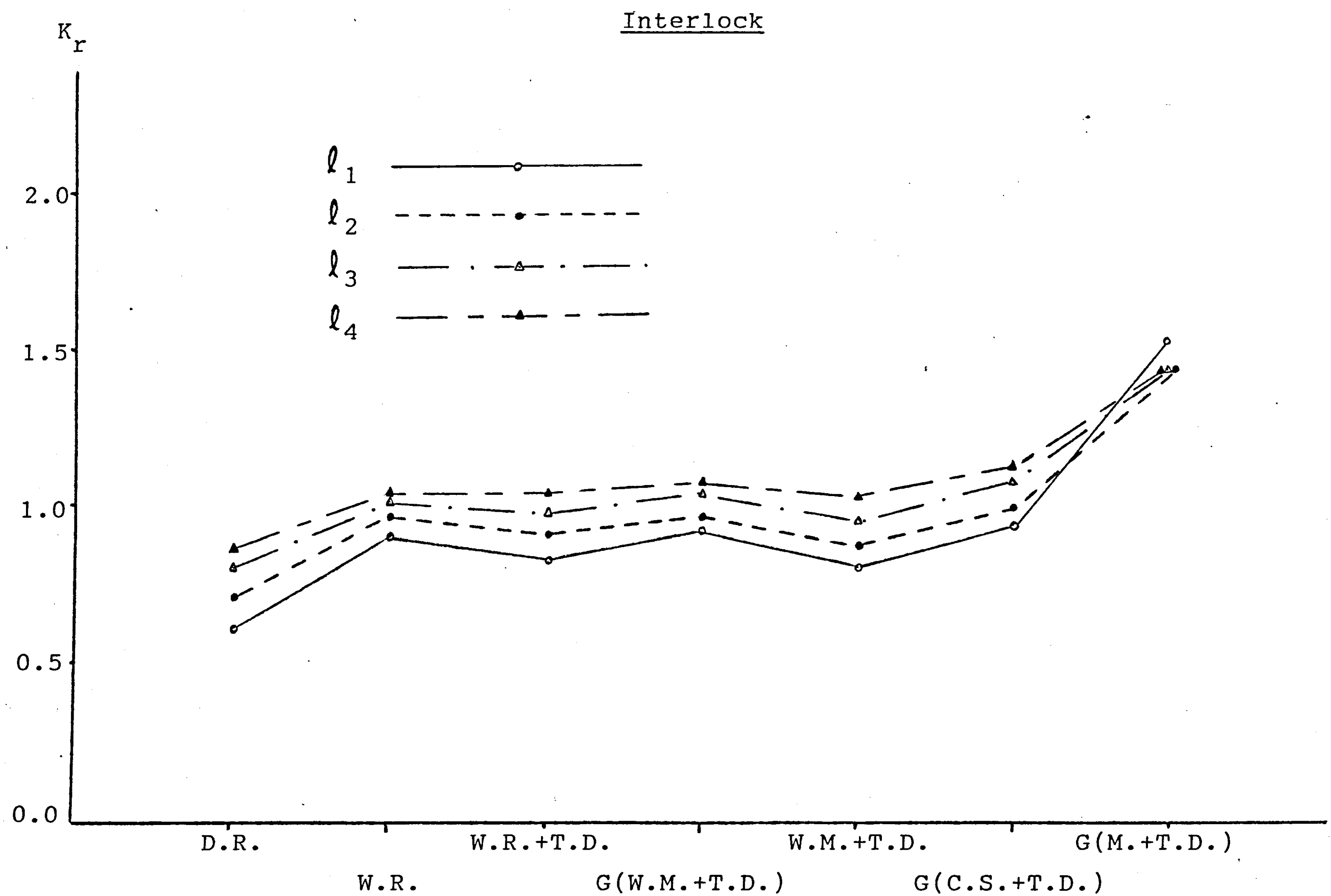
i) For the interlock structures in all states of relaxation the "K_r" value decreases significantly with increase in stitch length, but this effect decreases with further relaxation treatment. Thus for the interlock structure, not only does the "K_s" value change with stitch length, but also the width/length ratio of the loop. For this structure the loop shape is not constant with changes in stitch length. Again, this is a point which has not been picked out by previous workers.

ii) In the case of all the other structures (plain and rib), observation reveals that in the dry relaxed state, the "K_r" value also changes with stitch length (decreasing in all cases with increase in stitch length), but this effect decreases with further relaxation.

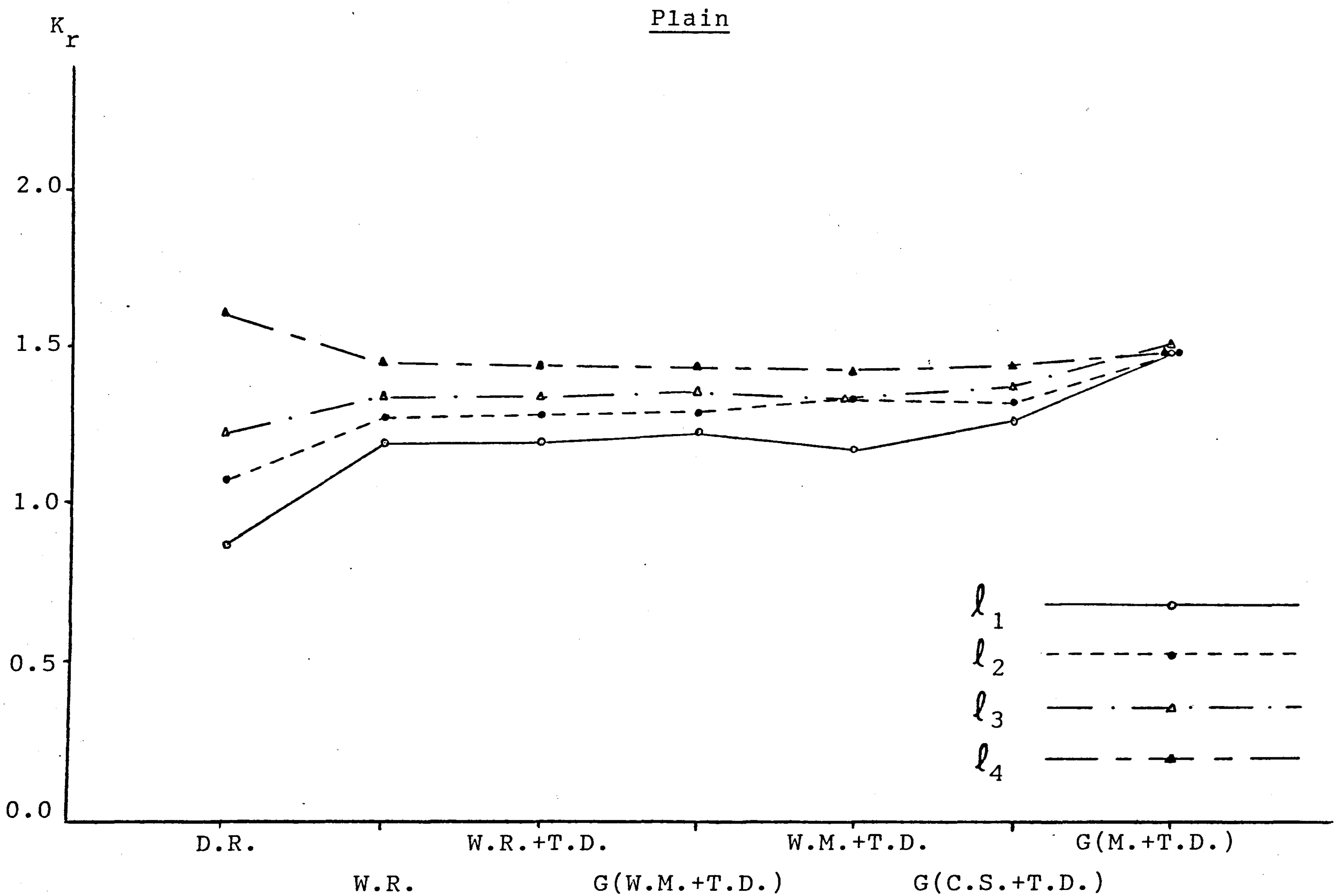
The traditional explanation of these type of effects is that in the early stage of relaxation, the dimensional changes have not been sufficient to overcome the distortion imposed on the loop shape during knitting, and that complete relaxation is required before the "K_r" value attains a constant value.

The slopes, intercept and correlations of the best fit lines and their formulae relating "K_r" with stitch length for all structures have been found by a computer program[58] and the detailed results are given in appendices 33 to 37.

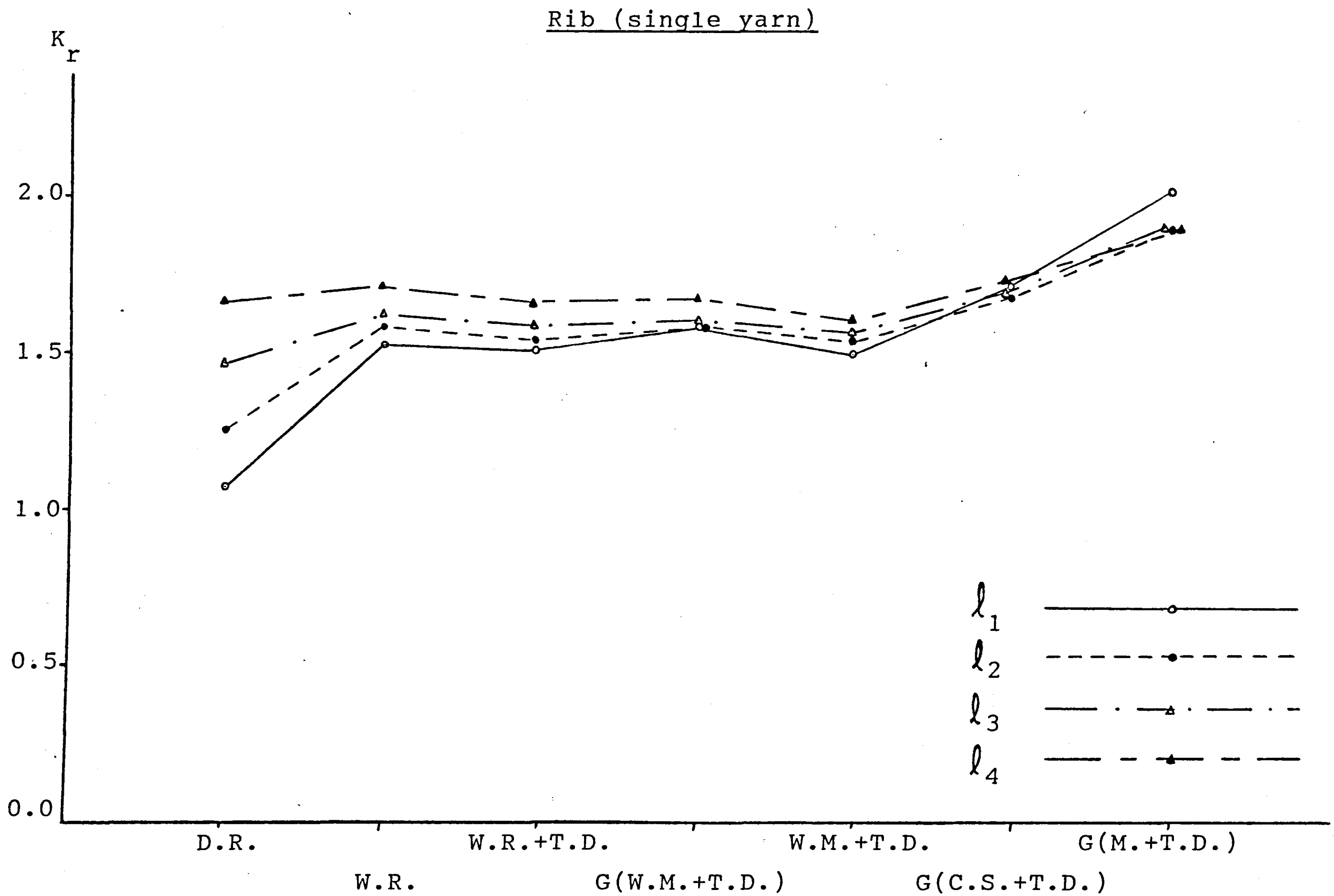
Examination of the "K_r" values for all the fabrics after complete relaxation (i.e., after the G(W.M.+T.D.) treatment) indicates that the range in "K_r" value from tightest to slackest fabrics although small is significant, increasing in value in all cases with decrease in stitch length.



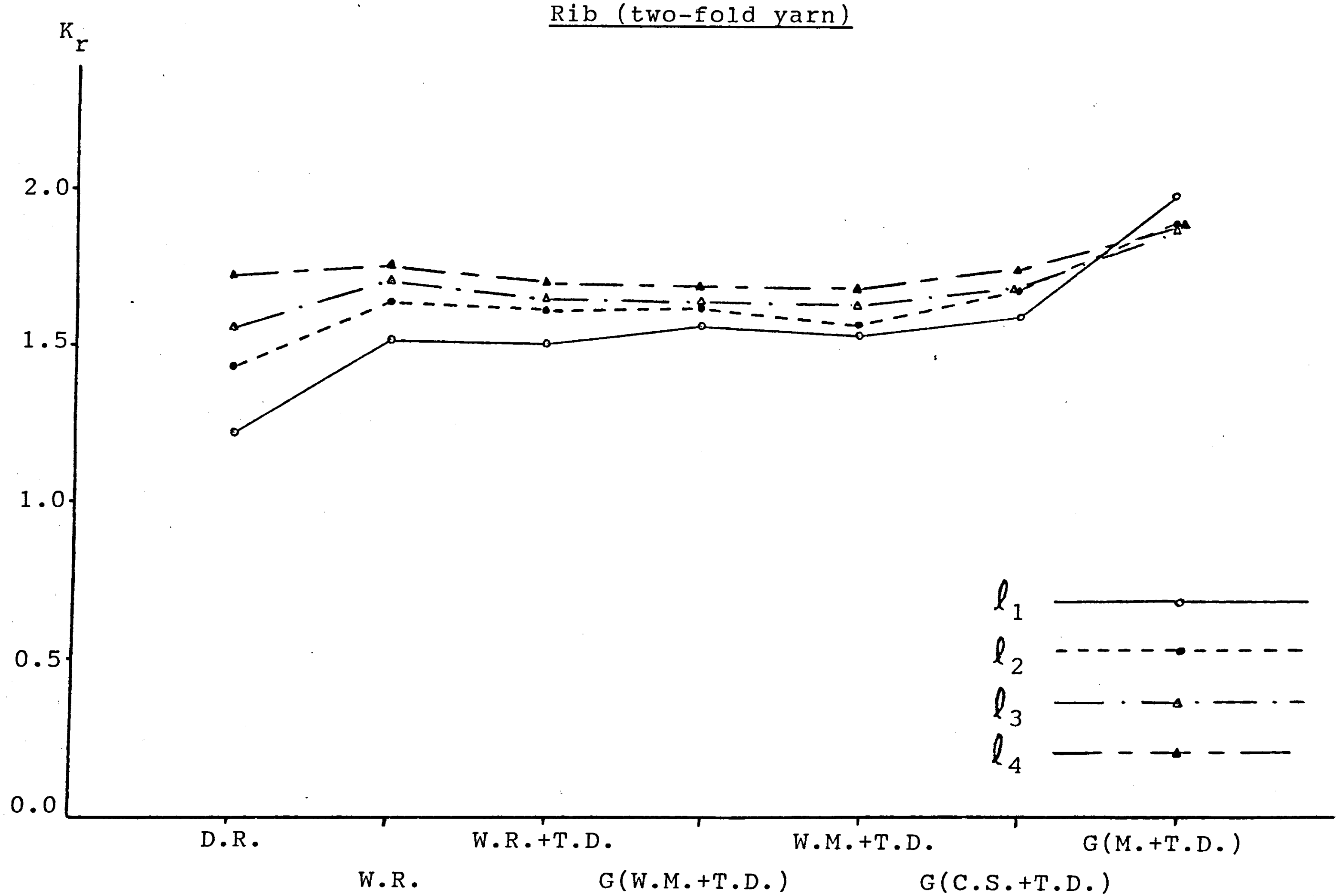
Figure(7.11) "K_r" values versus different relaxation treatments.



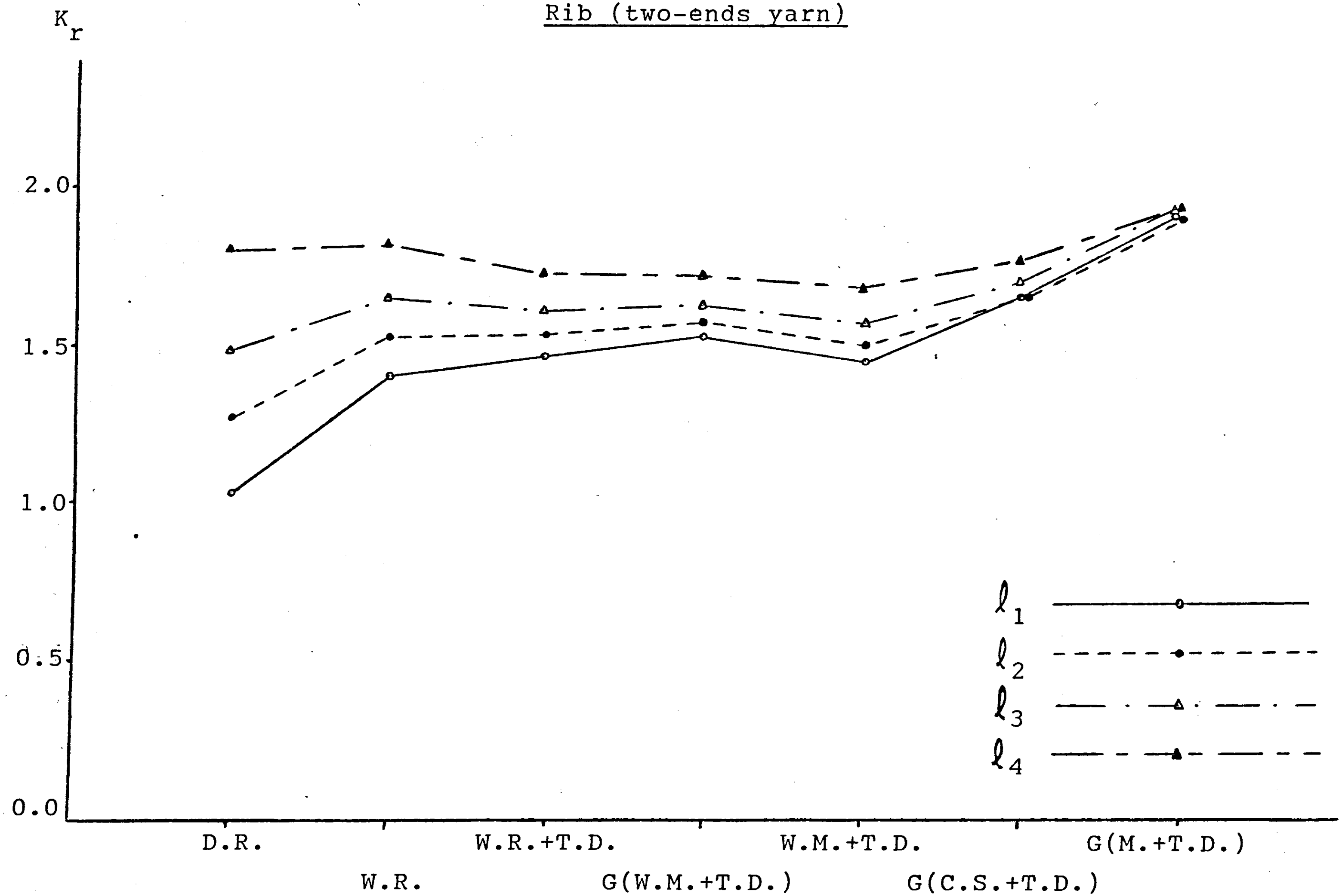
Figure(7.12) "K_r" values versus different relaxation treatments.



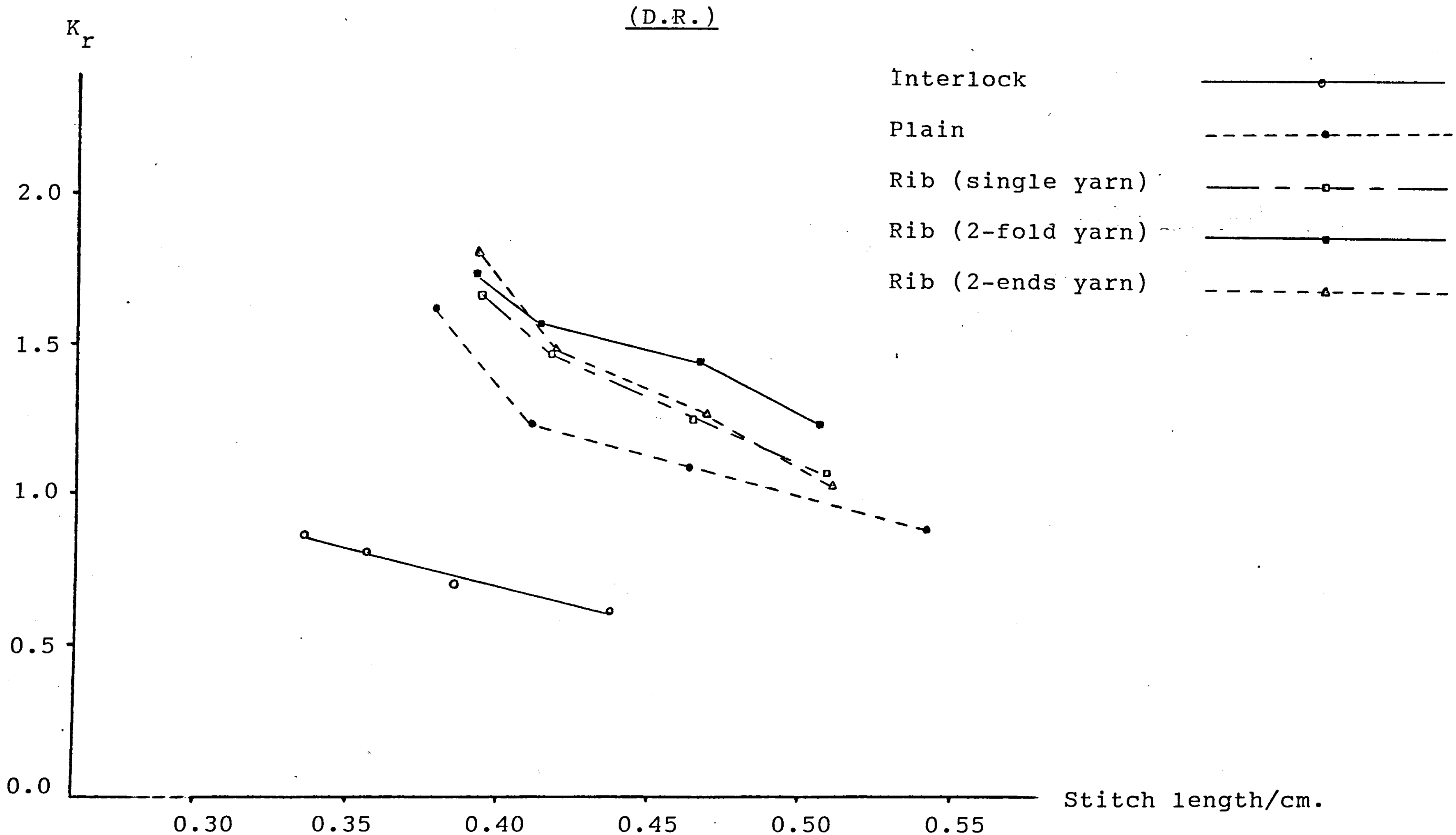
Figure(7.13) "K_r" values versus different relaxation treatments.



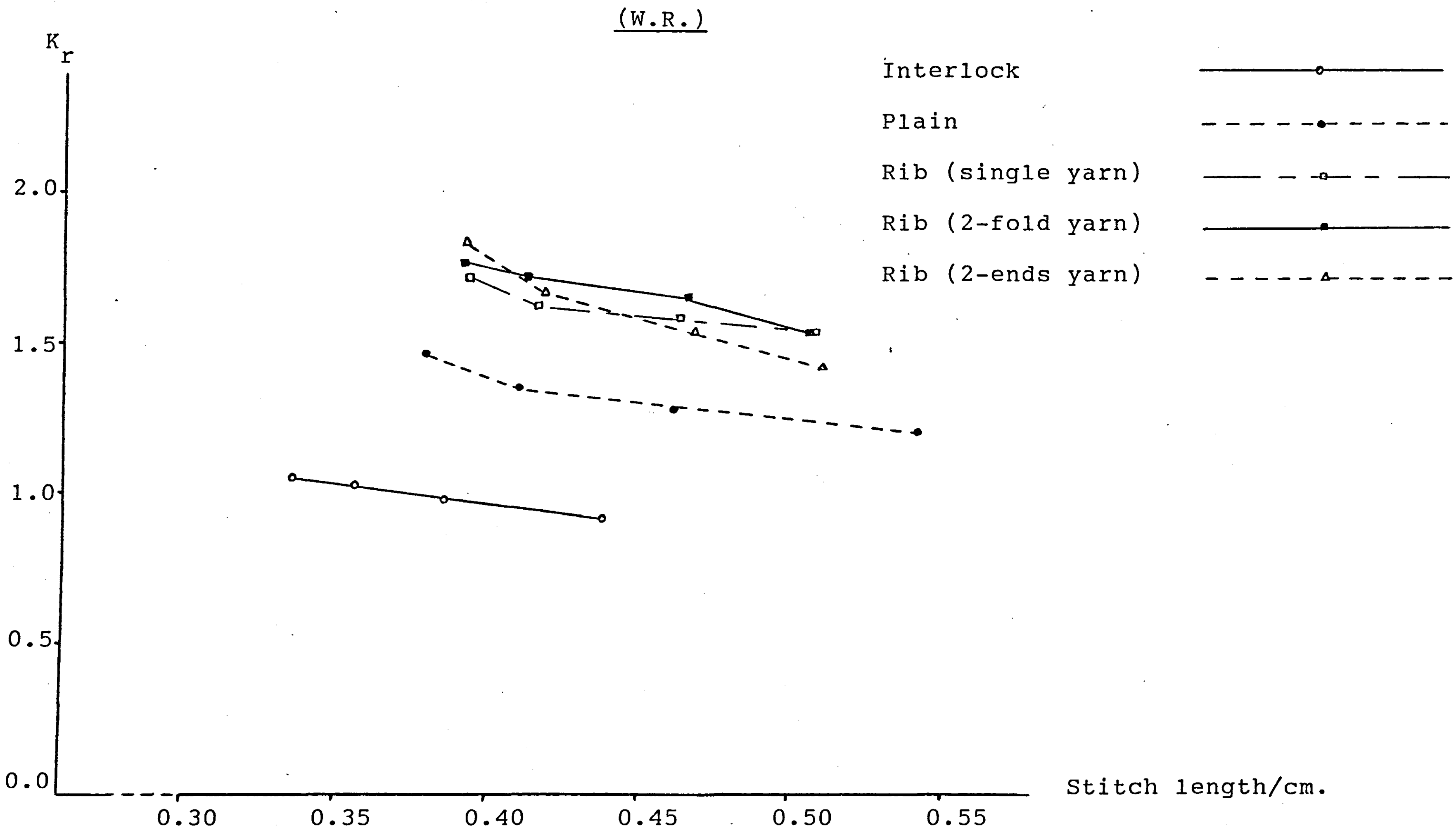
Figure(7.14) "K_r" values versus different relaxation treatments.



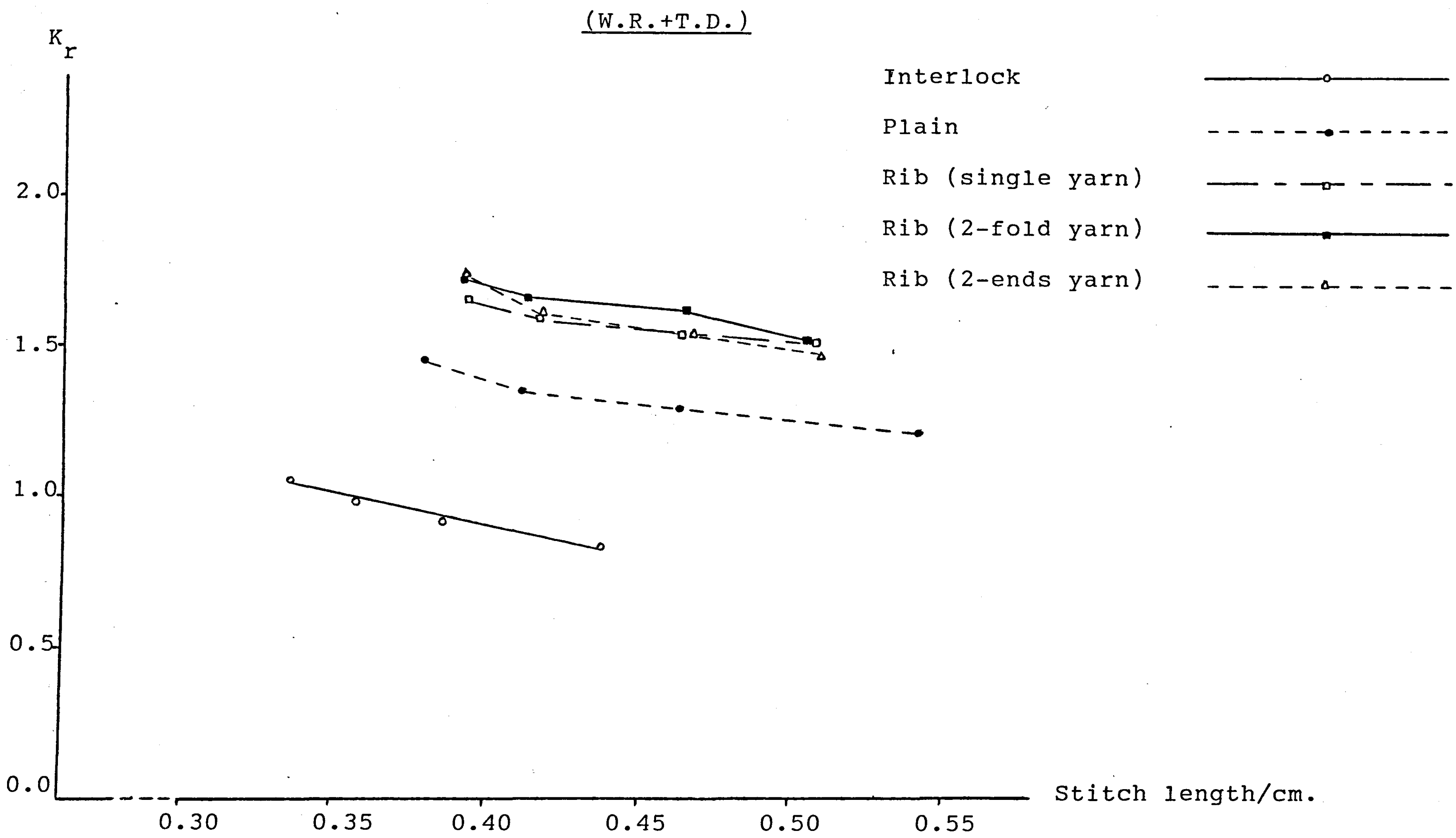
Figure(7.15) "K_r" values versus different relaxation treatments.



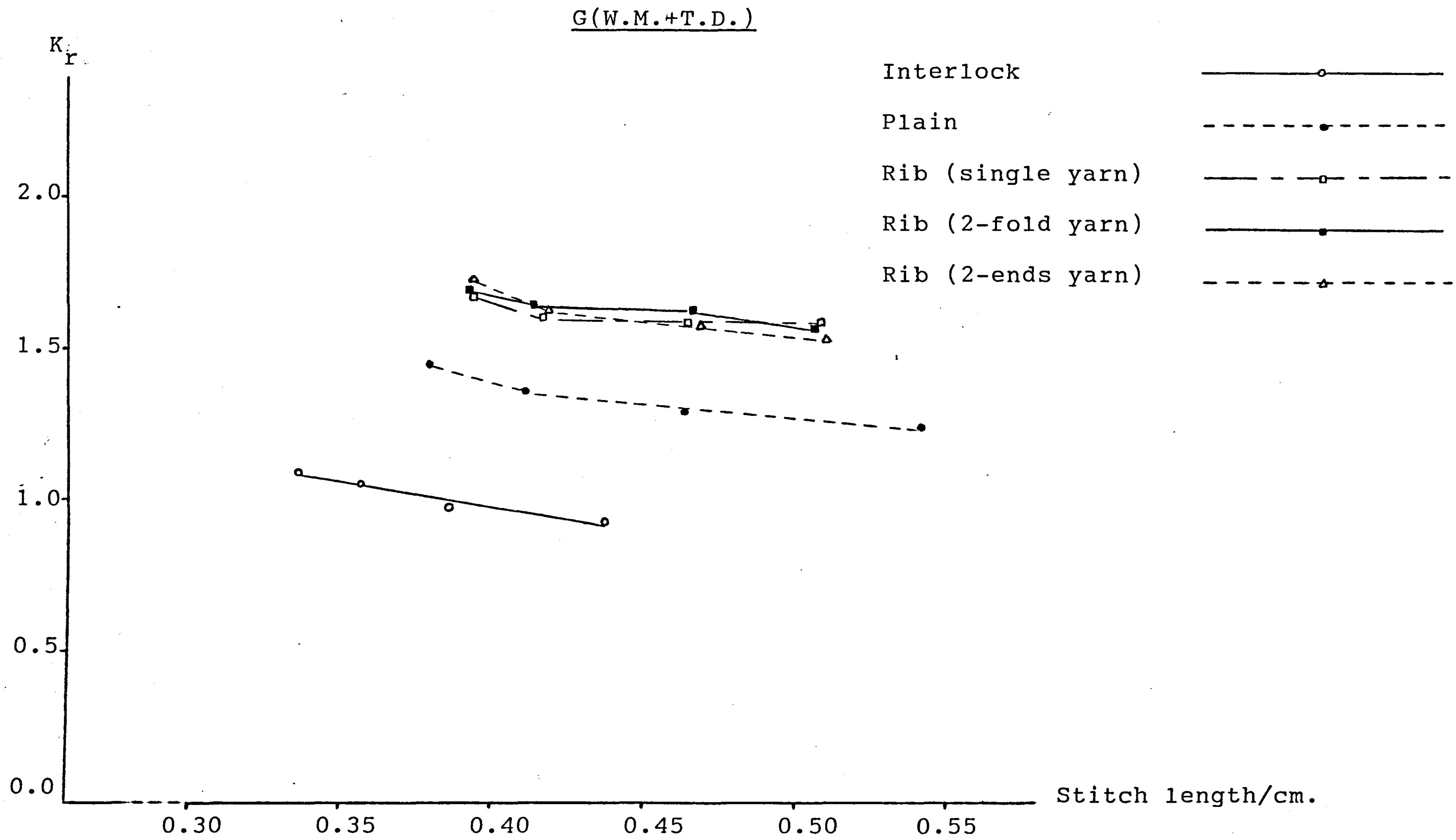
Figure(7.16) "K_r" values versus stitch length.



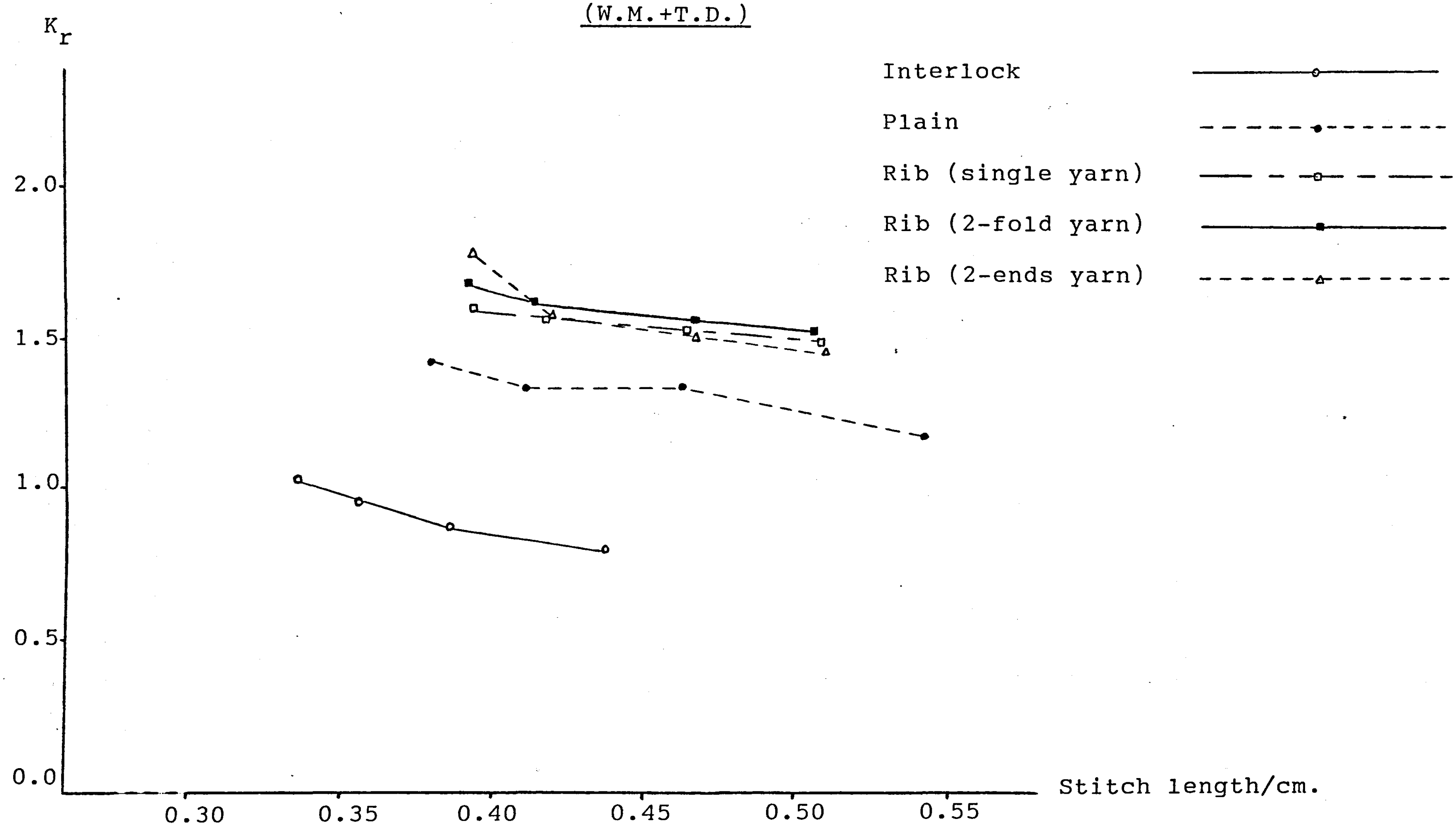
Figure(7.17) "K_r" values versus stitch length.



Figure(7.18) "K_r" values versus stitch length.



Figure(7.19) "K_r" values versus stitch length.



Figure(7.20) "K_r" values versus stitch length.

VII.2 The Effect Of Different Relaxation Treatments Conditions And Stitch Length On The Area Shrinkage

VII.2.1 Introduction

In order to determine the effect of different relaxation treatments on the fabric area shrinkage and study the role of stitch length on the same property, it was decided to calculate the percentage area shrinkage of each sample from their width and length measurements given in appendices 2 to 26. For this purpose a computer program was produced in Basic Language (see Appendix 61) and the results were derived and recorded in Tables (7.13) to (7.17).

The obtained results (i.e., area shrinkage percentage (A.S.%), for different stitch lengths of each structure) were plotted against the state of relaxation. These graphs are shown in Figures (7.21) to (7.25).

VII.2.2 Analysis And Discussion Of The Effect Of Relaxation On Area Shrinkage (A.S.%)

The information given in Tables (7.13) to (7.17) and plotted in Figures (7.21) to (7.25) simply confirm the facts mentioned under the discussion of change in "K_s" (i.e., that most of the area shrinkage occurs during the initial dry and wet relaxation processes).

(D.R.)

Sample	Length (cm.)	Width (cm.)	Area (cm.^{2})	Area shrinkage (cm.^{2})	Area shrinkage percentage
I.1	24.5	24.0	588.0	37.0	5.92%
I.2	24.9	24.6	612.5	12.5	1.99%
I.3	24.9	24.7	615.0	10.0	1.59%
I.4	24.8	25.0	620.0	5.0	0.80%
P.1	24.9	25.0	622.5	2.5	0.40%
P.2	25.0	25.0	625.0	0.0	0.00%
P.3	25.0	25.0	625.0	0.0	0.00%
P.4	24.9	24.9	620.0	5.0	0.79%
R.1.1	24.7	25.0	617.5	7.5	1.20%
R.1.2	24.9	24.7	615.0	10.0	1.59%
R.1.3	24.9	24.9	620.0	5.0	0.79%
R.1.4	24.8	24.8	615.0	10.0	1.59%
R.2.1	24.8	25.0	620.0	5.0	0.80%
R.2.2	24.9	24.9	620.0	5.0	0.79%
R.2.3	24.9	24.9	620.0	5.0	0.79%
R.2.4	24.8	24.9	617.5	7.5	1.19%
R.3.1	24.7	24.8	612.6	12.4	1.99%
R.3.2	24.8	24.6	610.1	14.9	2.38%
R.3.3	24.8	24.7	612.6	12.4	1.99%
R.3.4	24.9	24.5	610.0	15.0	2.39%

Table(7.13) The fabrics' dimensions after dry relaxation.

(W.R.)

Sample	Length (cm.)	Width (cm.)	Area (cm^2)	Area shrinkage ($cm.^2$)	Area shrinkage percentage
I.1	18.6	27.1	504.1	120.9	19.35%
i.2	19.1	25.7	490.9	134.1	21.46%
I.3	19.9	24.8	493.5	131.5	21.03%
I.4	19.9	24.4	485.6	139.5	22.31%
P.1	20.1	27.4	550.7	74.3	11.88%
P.2	21.0	25.0	525.0	100.0	16.00%
P.3	21.4	23.5	502.9	122.1	19.53%
P.4	23.8	21.5	511.7	113.3	18.12%
R.1.1	19.3	27.8	536.5	88.5	14.15%
R.1.2	20.2	25.3	511.1	113.9	18.23%
R.1.3	21.1	23.3	491.6	133.4	21.33%
R.1.4	21.7	22.3	483.9	141.1	22.57%
R.2.1	20.0	25.1	502.0	123.0	19.68%
R.2.2	20.9	23.9	499.5	125.5	20.07%
R.2.3	21.1	23.2	489.5	135.5	21.67%
R.2.4	21.8	22.3	486.1	138.9	22.21%
R.3.1	20.1	27.5	552.7	72.3	11.56%
R.3.2	20.8	24.9	517.9	107.1	17.13%
R.3.3	20.8	23.1	480.5	144.5	23.12%
R.3.4	21.9	21.8	477.4	147.6	23.61%

Table(7.14) The fabrics' dimensions after wet relaxation.

(W.R.+T.D.)

Sample	Length (cm.)	Width (cm.)	Area ($cm.^2$)	Area shrinkage ($cm.^2$)	Area shrinkage percentage
I.1	17.6	23.3	410.1	214.9	34.38%
I.2	17.9	22.6	404.5	220.5	35.27%
I.3	18.7	22.5	420.7	204.3	32.68%
I.4	18.7	22.8	426.4	198.6	31.78%
P.1	18.8	25.8	485.0	140.0	22.39%
P.2	20.0	23.9	478.0	147.0	23.52%
P.3	20.5	22.5	461.2	163.8	26.20%
P.4	23.2	20.8	482.6	142.4	22.79%
R.1.1	17.9	25.5	456.4	168.6	26.96%
R.1.2	19.0	23.2	440.8	184.2	29.47%
R.1.3	20.0	21.6	432.0	193.0	30.88%
R.1.4	20.7	20.6	426.4	198.6	31.77%
R.2.1	18.9	23.5	444.1	180.9	28.93%
R.2.2	19.7	22.2	437.3	187.7	30.02%
R.2.3	20.5	21.7	444.8	180.2	28.82%
R.2.4	21.2	21.0	445.2	179.8	28.76%
R.3.1	18.3	26.0	475.8	149.2	23.87%
R.3.2	19.6	23.6	462.6	162.4	25.99%
R.3.3	20.0	21.7	434.0	191.0	30.56%
R.3.4	21.5	20.3	436.4	188.6	30.16%

Table(7.15) The fabrics' dimensions after wet relaxation and tumble drying.

G(W.M.+T.D.)

Sample	Length (cm.)	Width (cm.)	Area (cm^2)	Area shrinkage ($cm.^2$)	Area shrinkage percentage
I.1	17.2	25.6	440.3	184.7	29.54%
I.2	17.5	23.7	414.7	210.3	33.64%
I.3	18.2	23.3	424.1	200.9	32.15%
I.4	18.3	23.3	426.4	198.6	31.77%
P.1	18.6	26.2	487.3	137.7	22.02%
P.2	19.9	24.1	479.6	145.4	23.26%
P.3	20.4	22.8	465.1	159.9	25.58%
P.4	23.3	20.8	484.6	140.4	22.45%
R.1.1	17.8	26.7	475.3	179.7	23.95%
R.1.2	18.8	23.7	445.6	179.4	28.71%
R.1.3	19.7	21.6	425.5	199.5	31.91%
R.1.4	20.4	20.5	418.2	206.8	33.08%
R.2.1	18.4	23.6	434.2	190.8	30.52%
R.2.2	19.3	21.9	422.7	202.3	32.37%
R.2.3	20.1	21.2	426.1	198.9	31.82%
R.2.4	20.8	20.4	424.3	200.7	32.10%
R.3.1	17.8	26.6	473.5	151.5	24.24%
R.3.2	19.1	23.6	450.8	174.2	27.87%
R.3.3	19.5	21.4	417.3	207.7	33.23%
R.3.4	21.0	19.7	413.7	211.3	33.80%

Table(7.16) The fabrics' dimensions after washing and tumble drying.

(W.M.+T.D.)

Sample	Length (cm.)	Width (cm.)	Area (cm^2)	Area shrinkage ($cm.^2$)	Area shrinkage percentage
I.1	17.4	22.6	393.2	231.8	37.08%
I.2	17.7	21.7	384.1	240.9	38.54%
I.3	18.3	21.4	391.6	233.4	37.34%
I.4	18.4	22.2	408.5	216.5	34.64%
P.1	18.9	25.4	480.1	145.0	23.19%
P.2	19.4	24.3	471.4	153.6	24.57%
P.3	20.7	22.6	467.8	157.2	25.14%
P.4	23.4	20.6	482.0	143.0	22.87%
R.1.1	18.0	25.6	460.8	164.2	26.27%
R.1.2	18.9	23.0	434.7	190.3	30.44%
R.1.3	20.0	21.3	426.0	199.0	31.84%
R.1.4	20.9	20.1	420.1	204.9	32.78%
R.2.1	18.9	23.9	451.7	173.3	27.72%
R.2.2	20.0	21.8	436.0	189.0	30.24%
R.2.3	20.9	21.8	455.6	169.4	27.10%
R.2.4	21.3	20.8	443.0	182.0	29.11%
R.3.1	18.4	26.1	480.2	144.8	23.16%
R.3.2	19.8	23.4	463.3	161.7	25.86%
R.3.3	20.1	21.3	428.1	196.9	31.49%
R.3.4	21.5	19.7	423.5	201.5	32.23%

Table(7.17) The fabrics' dimensions after washing and tumble drying immediately after dry relaxation.

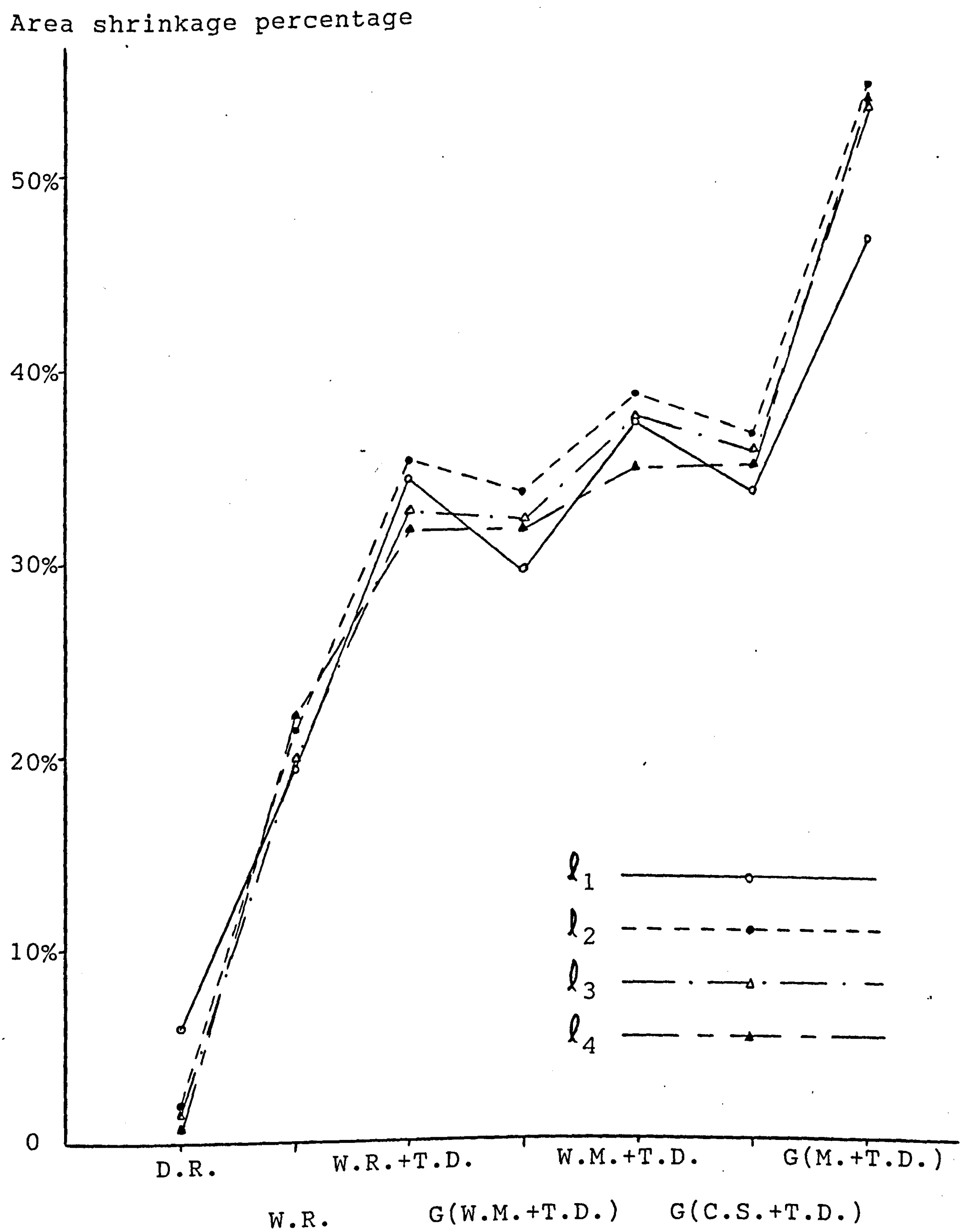
However the shrinkage results are useful in being able to compare the area shrinkage which occurs in the different structures as they approach these completely relaxed state.

Observation of the graph of A.S.% against relaxation states for plain fabric, Figure(7.22) reveals that its relaxation area shrinkage was considerably lower than that of the other structures. The figures for area shrinkage of the different structures are given in Table(7.18).

Structure	Percentage area shrinkage
interlock	32%
plain	24%
rib (single yarn)	29%
rib (two-fold yarn)	31%
rib (two-ends yarn)	29%

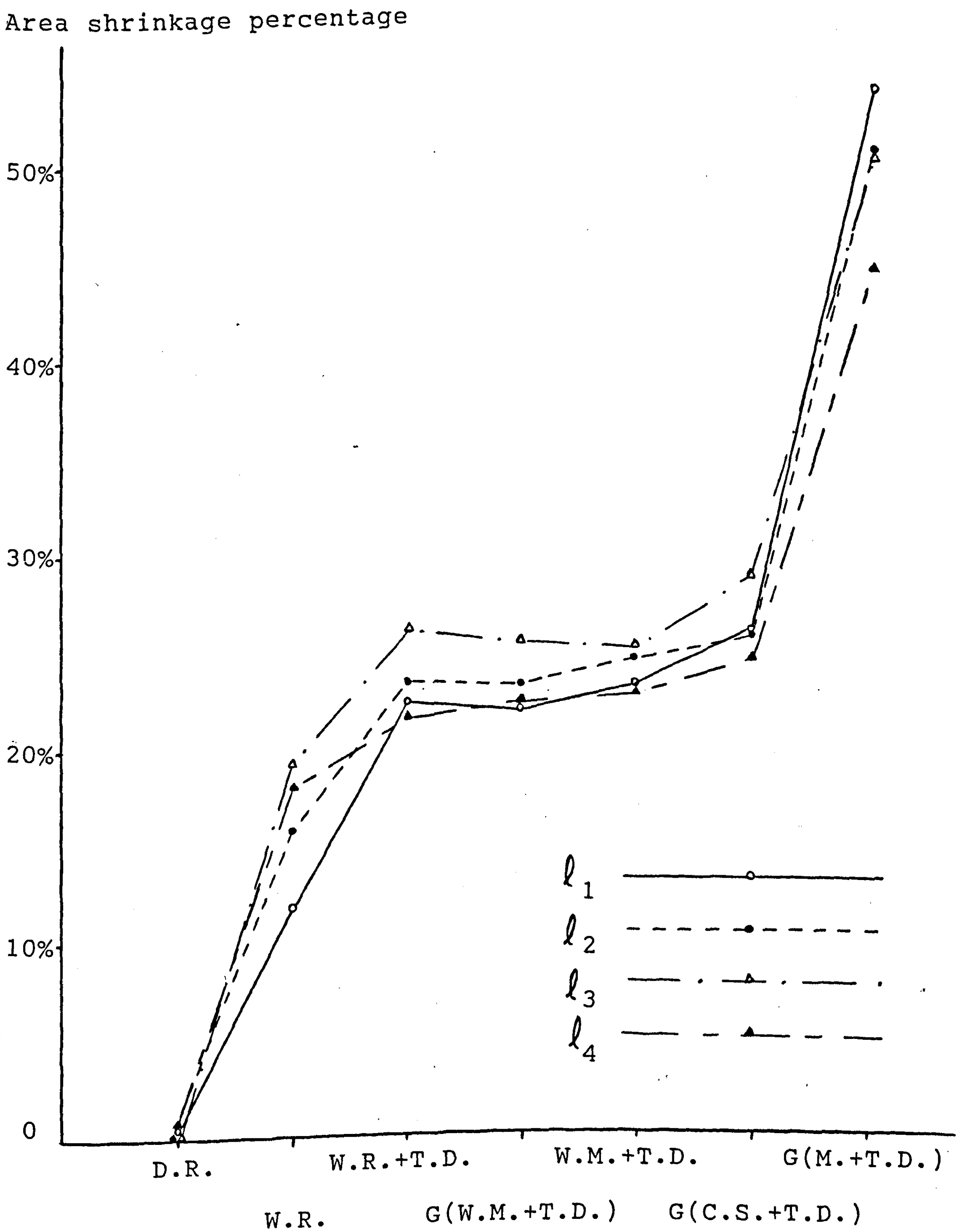
Table(7.18) The figures of area shrinkage for different cotton structures after washing and tumble drying.

Interlock



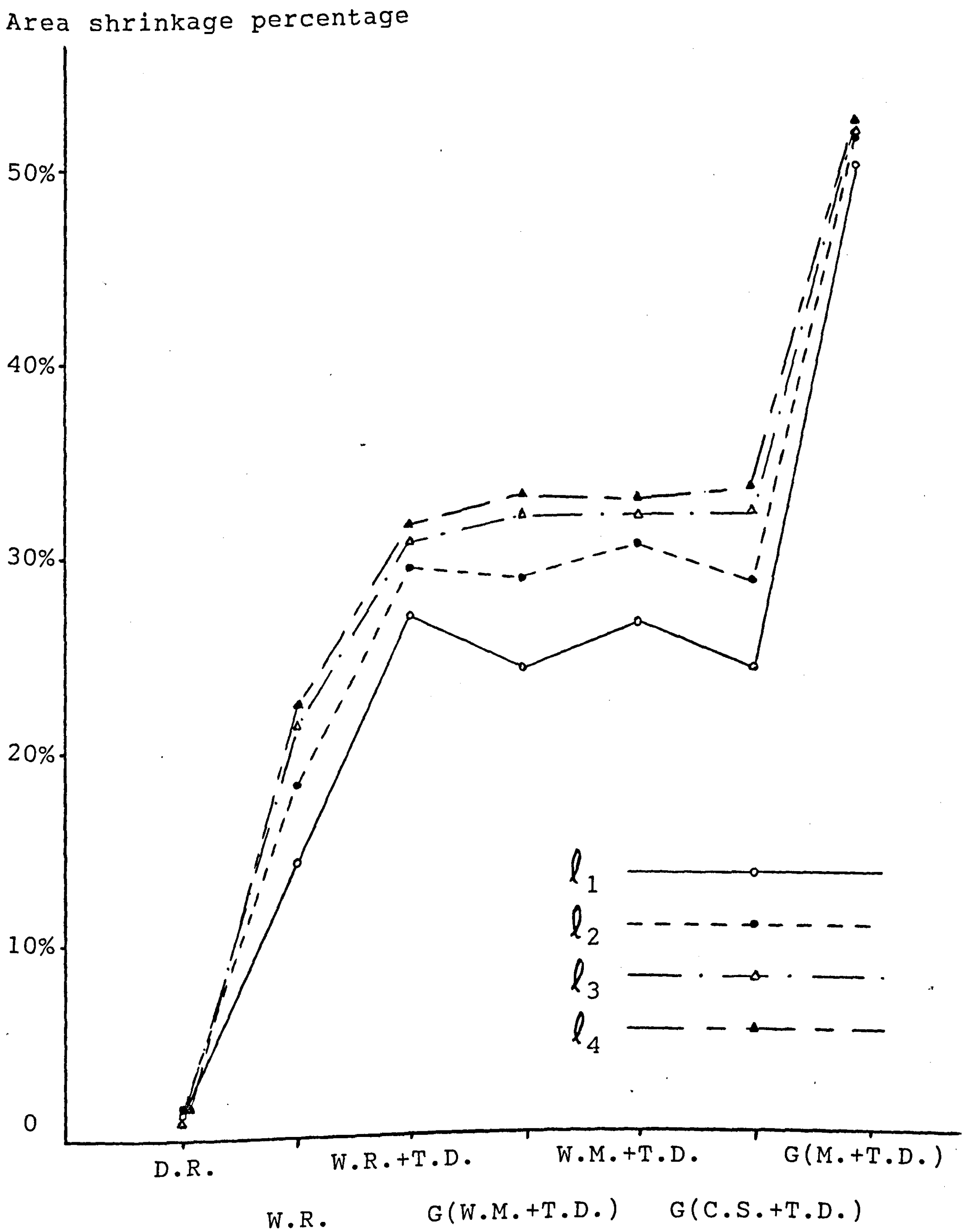
Figure(7.21) The area shrinkage percentage versus different relaxation treatments.

Plain



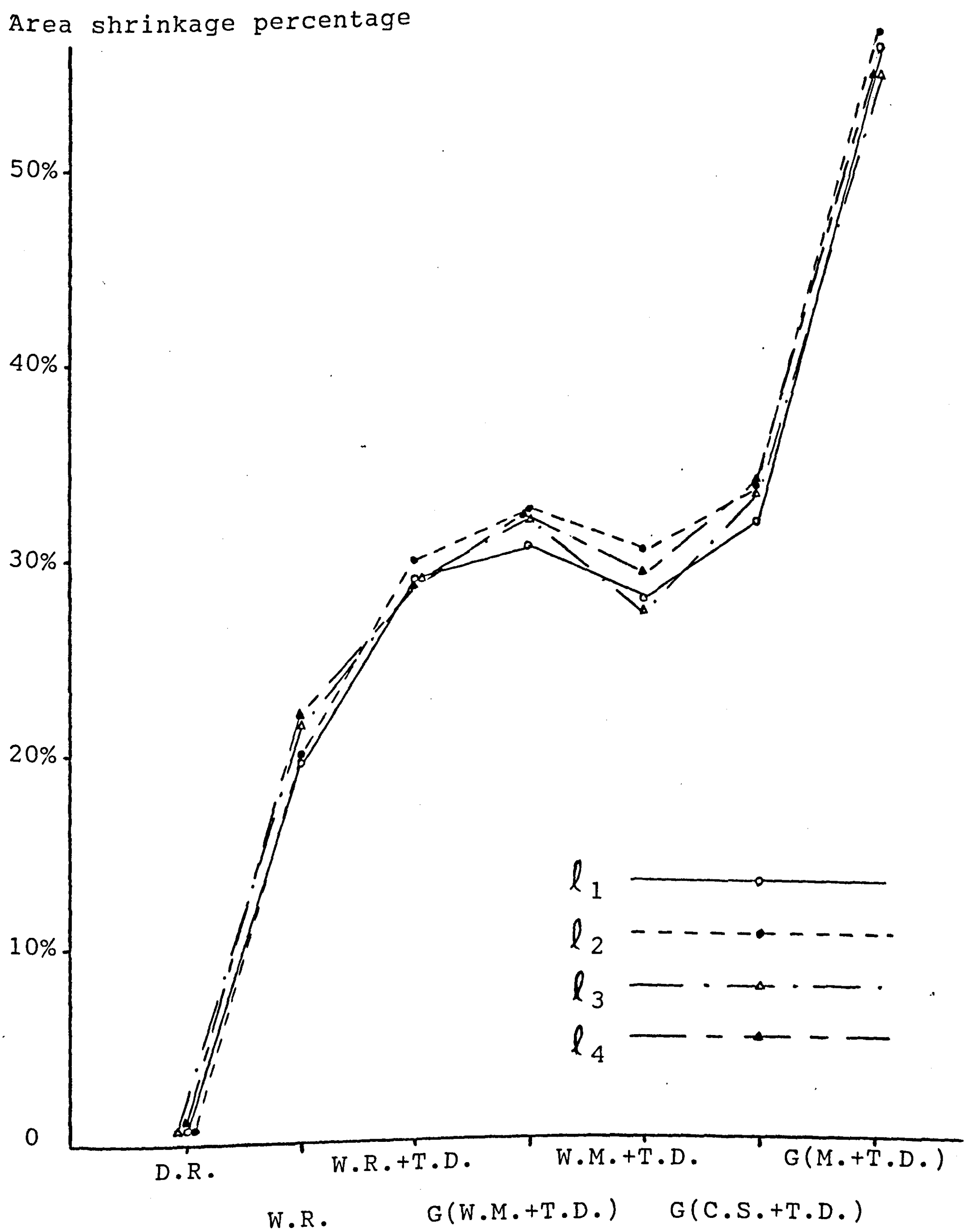
Figure(7.22) The area shrinkage percentage versus different relaxation treatments.

Rib (single yarn)



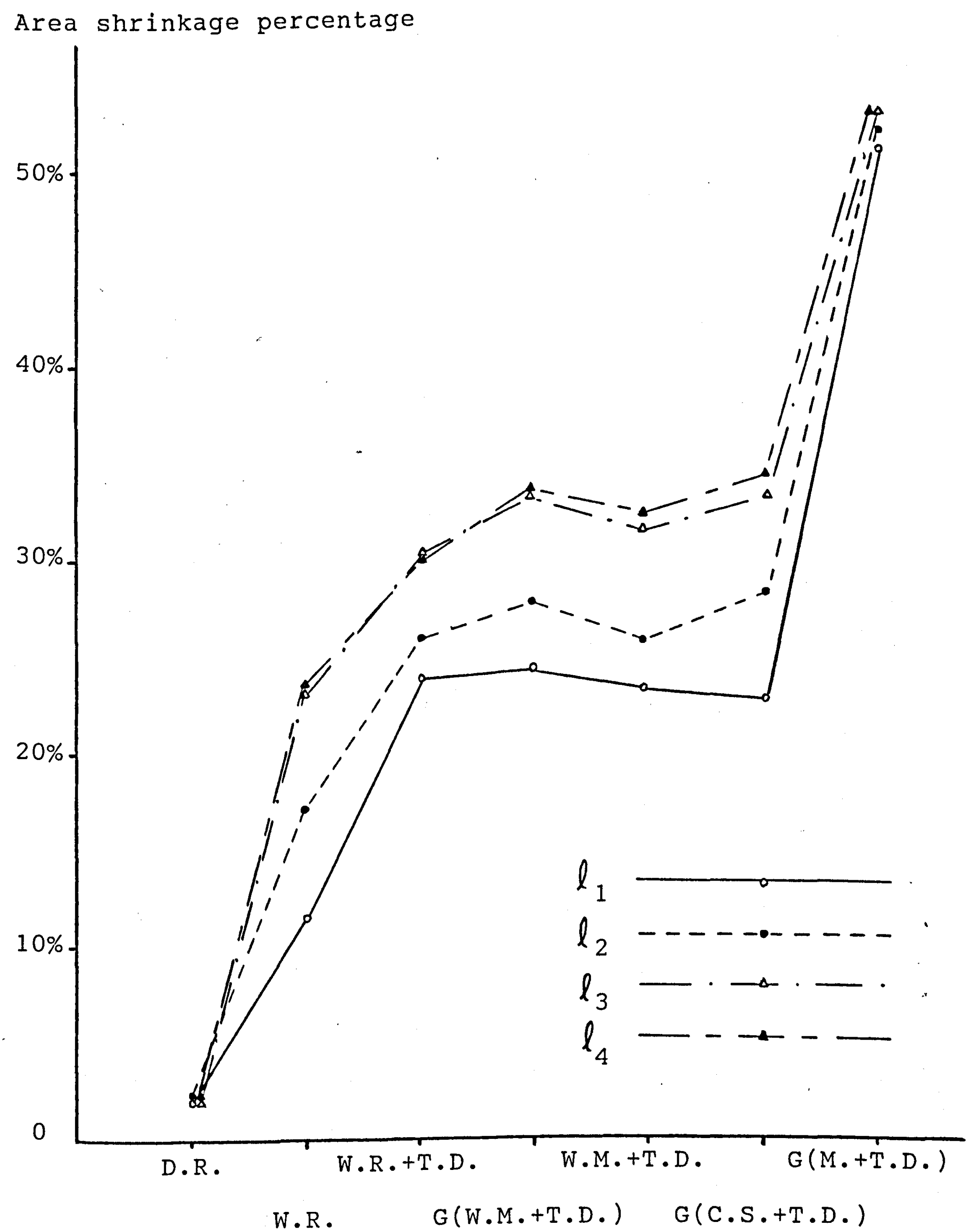
Figure(7.23) The area shrinkage percentage versus different relaxation treatments.

Rib (two-fold yarn)



Figure(7.24) The area shrinkage percentage versus different relaxation treatments.

Rib (two-ends yarn)



Figure(7.25) The area shrinkage percentage versus different relaxation treatments.

VII.3 The Effect Of Relaxation Treatments On Yarn Shrinkage

VII.3.1 Introduction

Leigh[3], found that two-fold wool yarns exhibit a much greater shrinkage (of the order of 4.6%) in a wet relaxed fabric than singles wool yarn (up to 2%). He also suggested that, as a consequence of the greater shrinkage of the two-fold yarn, the fabrics knitted from such yarns may be expected to exhibit a greater total percentage area shrinkage than fabrics knitted from a similar singles yarn since total fabric area shrinkage is due to two effects, loop length change and loop shape change, and the shrinkage due to loop shape change will be the same in both fabrics.

As indicated in section VII.1.1.iv, the "K_s" value of the rib fabrics knitted from a two-fold cotton yarn is lower than that for the fabrics knitted with a single yarn, and it was suggested that this phenomenon might be attributable to the shrinkage behaviour of single and two-fold yarns. It was decided to investigate this point in greater detail, to see if an acceptable explanation could be given.

VII.3.2 Experimental Details And Results

In order to find the shrinkage percentage of the yarn used to knit the fabrics, during a relatively complete relaxation, i.e. in the standard washing machine and then tumble drying (W.M. + T.D.), the following additional stitch length measurements were made.

All the fabrics were measured for stitch length after the washing and tumble drying treatment by measuring the length of yarn between the marker points, using a HATRA course length tester and dividing the measured unroved lengths by the number of wales between the marker points and the resultant stitch lengths are given in Table(7.19).

These results indicate that the two-fold yarn has a higher shrinkage than the single yarn.

As may be seen from Figure(7.10) the "K_s" values of the rib fabrics after washing and tumble drying treatment were as follows:

rib (single yarn)	18.7;
rib (two-fold yarn)	17.0;
rib (two-ends yarn)	19.1.

If the measured yarn shrinkage is applied to give the actual "K_s" values of the fabrics (2.2% in the case of the singles and 2.7% in the case of the two-fold), this would reduce the "K_s" value of the rib fabrics knitted with the two-fold yarn by 5.3% and that of the singles yarn by 4.3% thus giving greater difference in "K_s" values than that already observed. This effect is obvious when the results

Sample	Original stitch length (cm.)	Shrunk stitch length (cm.)	Yarn shrinkage percentage
I.1	0.436	0.424	2.75%
I.2	0.385	0.378	1.82%
I.3	0.357	0.353	0.56%
I.4	0.335	0.330	1.49%
P.1	0.541	0.523	3.33%
P.2	0.463	0.453	2.16%
P.3	0.411	0.408	0.73%
P.4	0.379	0.367	3.17%
R.1.1	0.509	0.500	1.77%
R.1.2	0.464	0.456	1.72%
R.1.3	0.417	0.408	2.16%
R.1.4	0.394	0.386	2.03%
R.2.1	0.505	0.493	2.38%
R.2.2	0.466	0.451	3.22%
R.2.3	0.413	0.405	1.94%
R.2.4	0.392	0.380	3.06%
R.3.1	0.510	0.497	2.55%
R.3.2	0.468	0.457	2.35%
R.3.3	0.419	0.408	2.62%
R.3.4	0.393	0.384	2.29%

Table(7.19) The figures of yarn shrinkage percentage of single and two-fold cotton yarns in different structures after washing and tumbling.

are given in graph form as in Figure(7.26). Table(7.20) shows the "K_s", "K_c", "K_w", and "K_r" values of different structures which were calculated for the shrunk stitch length.

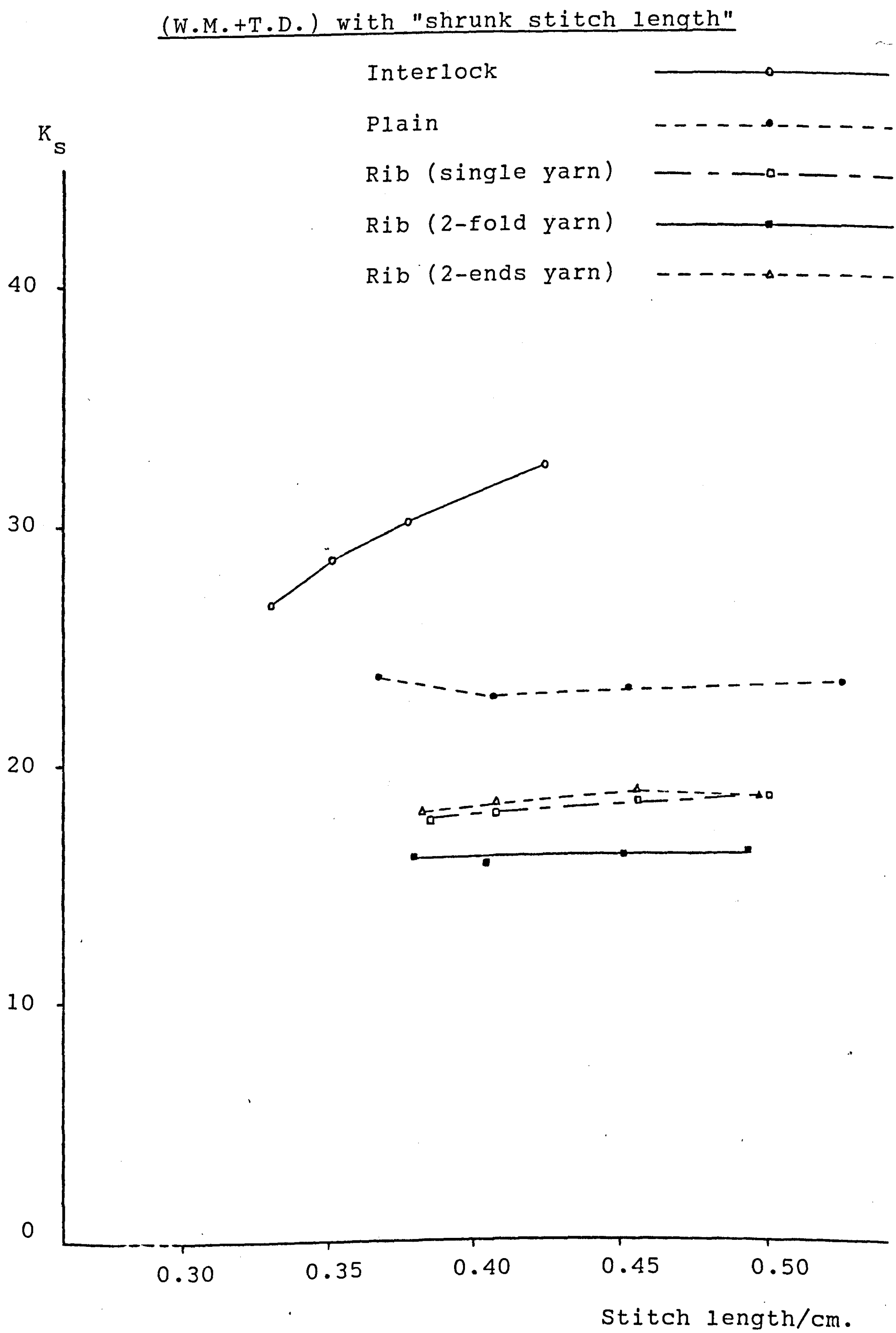
Therefore, the difference between the "K_s" value of the fabrics knitted with two-fold and single cotton yarns can not be explained as due to the shrinkage of the yarns. Thus, the differences in "K_s" value must be associated with slight difference in loop shape as the result of using the different yarn construction.

This point is considered again in the next chapter after more complete relaxation treatments had been given to the fabrics,i.e., after caustic soda (sodium hydroxide solution) and mercerizing (concentrated sodium hydroxide solution) treatments.

(W.M.+T.D.) with "shrunk stitch length"

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.424	12.13	14.89	5.14	6.31	32.47	0.81	2.35
I.2	0.378	13.67	15.46	5.16	5.84	30.19	0.88	2.64
I.3	0.353	14.86	15.47	5.24	5.46	28.64	0.96	2.83
I.4	0.330	16.00	15.36	5.28	5.06	26.76	1.04	3.03
P.1	0.523	10.05	8.50	5.25	4.44	23.36	1.18	1.91
P.2	0.453	12.37	9.14	5.60	4.14	23.20	1.35	2.20
P.3	0.408	13.55	10.09	5.52	4.11	22.75	1.34	2.45
P.4	0.367	15.88	11.09	5.82	4.07	23.71	1.43	2.72
R.1.1	0.500	10.61	7.03	5.30	3.51	18.64	1.50	2.00
R.1.2	0.456	11.69	7.59	5.33	3.46	18.44	1.54	2.19
R.1.3	0.408	13.00	8.26	5.30	3.37	17.87	1.57	2.45
R.1.4	0.386	13.83	8.58	5.33	3.31	17.68	1.61	2.59
R.2.1	0.493	10.21	6.59	5.03	3.24	16.35	1.54	2.02
R.2.2	0.451	11.20	7.11	5.05	3.20	16.19	1.57	2.21
R.2.3	0.405	12.61	7.68	5.10	3.11	15.88	1.64	2.46
R.2.4	0.380	13.76	8.10	5.22	3.07	16.09	1.69	2.63
R.3.1	0.497	10.52	7.16	5.22	3.55	18.60	1.46	2.01
R.3.2	0.457	11.72	7.73	5.35	3.53	18.92	1.51	2.18
R.3.3	0.408	13.23	8.33	5.39	3.39	18.34	1.58	2.45
R.3.4	0.384	14.37	8.50	5.51	3.26	18.01	1.69	2.60

Table(7.20) The dimensional parameters of the fabrics after washing and tumble drying immediately after dry relaxation.



Figure(7.26) "K_s" values versus shrunk stitch length.

CHAPTER VIII

THE EFFECT OF CAUSTIC SODA AND MERCERIZING TREATMENTS ON THE DIMENSIONAL PROPERTIES OF THE KNITTED FABRICS

VIII.1 Introduction

For these relaxations, samples from two groups of all the fabrics listed in Table(6.1) were taken. The first group were these previously relaxed under (D.R.), (W.R.), (W.R.+T.D.) and G(W.M.+T.D.) respectively. The second group were fabrics taken directly after dry relaxation. Each sample was prepared in the same way as mentioned in Chapter VI. The following treatments were applied to both groups of samples:

a) caustic soda treatment;

b) mercerizing treatment.

VIII.1.a Caustic Soda Treatment

The fabrics were subjected to a caustic soda treatment as detailed in Table(8.1). Two pieces of fabric were subjected to this treatment from each sample. The average of their measurements were used in the calculations. Only one of these pieces was subsequently subjected to the mercerizing treatment.

VIII.1.b Mercerizing Treatment

Details of the mercerizing treatment given after the caustic soda treatment, are given in Table(8.2).

1)	BOiled for 30 minutes in the Pegg Scouring machine with 2gram/litre caustic soda and 1 gram/litre synperonic B.D. solution (the liquor ratio was 30:1).
2)	Rinsed twice.
3)	Neutralised in 1% acetic acid.
4)	Rinsed twice.
5)	Centrifuged for a few minutes.
6)	Tumble dried in 70 $^{\circ}C$ for 60 minutes.
7)	Left on a flat table for 20 hours.

Table(8.1) Caustic soda procedure.

1)	The fabrics were laid out in the solution (25% sodium hydroxide solution) for 10 minutes.
2)	The fabrics were squeezed by passing the material between squeeze rollers.
3)	Rinsed twice.
4)	Neutralised in acetic acid.
5)	Rinsed twice.
6)	Tumble dried in 70 $^{\circ}C$ for 60 minutes.
7)	Left on a flat table for 20 hours.

Table(8.2) Mercerizing procedure.

VIII.2 Results And Discussion

VIII.2.1 "K_s" and "K_r" Values

The average results of C.P.cm. and W.P.cm. and the calculated values of "K_c", "K_w", "K_s" and "K_r" for both pieces, i.e.,

i) after caustic soda and,

ii) after caustic soda plus mercerizing,

are recorded in Tables (8.3) to (8.6). (Note: those fabrics subjected to the caustic soda treatment alone are designated as G(C.S.+T.D.) and those that were mercerized are designated G(M.+T.D.)). The graphs of "K_s" and "K_r" values against stitch length for each construction are illustrated in Figures (8.1) to (8.8), in G(C.S.+T.D.), G(M.+T.D.), (C.S.+T.D.) and (M.+T.D.) treatments respectively.

From general observation of these graphs and previous graphs, i.e., Figures (7.1) to (7.5) and Figures (7.11) to (7.15), which were plotted for "K_s" and "K_r" against different relaxation treatments, the following points may be observed.

VIII.2.1.1 "K_s" Values

i) After the G(C.S.+T.D.) treatment the "K_s" values increased for each structure, but the increase was only small. In contrast, after the G(M.+T.D.) treatment, G(C.S.+T.D.)

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.436	12.79	13.35	5.55	5.79	32.16	0.95	2.29
I.2	0.385	14.40	14.22	5.52	5.46	30.19	1.01	2.60
I.3	0.357	15.63	14.33	5.61	5.14	28.86	1.09	2.80
I.4	0.335	16.83	14.70	5.60	4.89	27.43	1.14	2.99
P.1	0.541	10.67	8.31	5.69	4.43	25.28	1.28	1.85
P.2	0.463	12.44	9.25	5.70	4.24	24.24	1.34	2.16
P.3	0.411	14.17	10.13	5.89	4.21	24.84	1.39	2.43
P.4	0.379	16.22	11.09	6.05	4.13	25.02	1.46	2.64
R.1.1	0.509	11.17	6.47	5.66	3.28	18.57	1.72	1.96
R.1.2	0.464	12.08	7.15	5.60	3.31	18.59	1.68	2.15
R.1.3	0.417	13.54	7.96	5.61	3.30	18.56	1.70	2.40
R.1.4	0.394	14.45	8.29	5.64	3.24	18.31	1.74	2.54
R.2.1	0.505	10.72	6.65	5.43	3.37	18.32	1.61	1.98
R.2.2	0.466	11.91	7.01	5.52	3.25	17.97	1.69	2.15
R.2.3	0.413	13.44	7.86	5.57	3.26	18.19	1.70	2.42
R.2.4	0.392	14.50	8.22	5.66	3.21	18.22	1.76	2.55
R.3.1	0.510	11.18	6.70	5.66	3.39	19.25	1.66	1.96
R.3.2	0.468	12.47	7.51	5.78	3.48	20.16	1.66	2.14
R.3.3	0.419	13.93	8.14	5.78	3.37	19.52	1.71	2.39
R.3.4	0.393	15.00	8.42	5.86	3.29	19.30	1.78	2.54

Table(8.3) The dimensional parameters of the fabrics after caustic soda treatment.

G(M.+T.D.)

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.436	18.19	11.68	7.89	5.06	40.01	1.55	2.29
I.2	0.385	20.51	13.92	7.87	5.34	42.09	1.47	2.60
I.3	0.357	21.25	14.52	7.62	5.21	39.76	1.46	2.80
I.4	0.335	22.48	15.50	7.48	5.16	38.63	1.45	2.99
P.1	0.541	14.62	9.77	7.80	5.21	40.73	1.49	1.85
P.2	0.463	16.11	10.78	7.39	4.94	36.58	1.49	2.16
P.3	0.411	17.76	11.63	7.38	4.83	35.74	1.52	2.43
P.4	0.379	19.25	12.77	7.18	4.76	34.20	1.50	2.64
R.1.1	0.509	14.92	7.38	7.56	3.74	28.30	2.02	1.96
R.1.2	0.464	15.56	8.15	7.21	3.78	27.30	1.90	2.15
R.1.3	0.417	16.99	8.89	7.05	3.68	26.01	1.91	2.40
R.1.4	0.394	17.84	9.38	6.97	3.66	25.58	1.90	2.54
R.2.1	0.505	14.85	7.46	7.52	3.78	28.47	1.99	1.98
R.2.2	0.466	15.66	8.24	7.26	3.82	27.78	1.90	2.15
R.2.3	0.413	17.11	9.10	7.10	3.77	26.81	1.88	2.42
R.2.4	0.392	18.20	9.57	7.11	3.74	26.62	1.90	2.55
R.3.1	0.510	15.12	7.86	7.66	3.98	30.54	1.92	1.96
R.3.2	0.468	16.45	8.58	7.63	3.98	30.38	1.91	2.14
R.3.3	0.419	17.73	9.10	7.35	3.77	27.78	1.94	2.39
R.3.4	0.393	18.61	9.52	7.27	3.72	27.08	1.95	2.54

Table(8.4) The dimensional parameters of the fabrics after mercerization.

(C.S.+T.D.)

Sample	l/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/l$
I.1	0.436	12.41	13.46	5.38	5.84	31.46	0.92	2.29
I.2	0.385	13.99	14.40	5.37	5.52	29.70	0.97	2.60
I.3	0.357	15.03	14.45	5.39	5.18	27.99	1.04	2.80
I.4	0.335	16.18	14.70	5.38	4.89	26.37	1.10	2.99
P.1	0.541	9.95	8.40	5.31	4.48	23.83	1.18	1.85
P.2	0.463	12.18	9.49	5.59	4.35	24.35	1.28	2.16
P.3	0.411	13.82	10.13	5.74	4.21	24.22	1.36	2.43
P.4	0.379	16.01	11.15	5.97	4.15	24.83	1.43	2.64
R.1.1	0.509	10.55	6.72	5.34	3.40	18.22	1.56	1.96
R.1.2	0.464	11.82	7.27	5.48	3.37	18.50	1.62	2.15
R.1.3	0.417	13.13	7.93	5.44	3.29	17.93	1.65	2.40
R.1.4	0.394	13.89	8.14	5.43	3.18	17.28	1.70	2.54
R.2.1	0.505	10.32	6.67	5.23	3.38	17.69	1.54	1.98
R.2.2	0.466	11.55	6.98	5.35	3.23	17.35	1.65	2.15
R.2.3	0.413	13.18	7.75	5.46	3.21	17.59	1.70	2.42
R.2.4	0.392	14.09	8.10	5.50	3.16	17.44	1.73	2.55
R.3.1	0.510	10.81	6.88	5.48	3.48	19.11	1.57	1.96
R.3.2	0.468	12.15	7.36	5.63	3.41	19.25	1.65	2.14
R.3.3	0.419	13.37	8.07	5.54	3.34	18.58	1.65	2.39
R.3.4	0.393	14.86	8.09	5.81	3.16	18.37	1.83	2.54

Table(8.5) The dimensional parameters of the fabrics after caustic soda treatment immediately after dry relaxation.

(M.+T.D.)

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.436	17.73	11.89	7.69	5.16	39.70	1.49	2.29
I.2	0.385	20.00	13.81	7.68	5.30	40.72	1.44	2.60
I.3	0.357	20.61	14.65	7.39	5.25	38.91	1.40	2.80
I.4	0.335	21.34	15.57	7.10	5.18	36.84	1.37	2.99
P.1	0.541	13.57	9.56	7.24	5.10	36.99	1.41	1.85
P.2	0.463	15.89	10.88	7.29	4.99	36.42	1.46	2.16
P.3	0.411	17.42	11.46	7.24	4.76	34.54	1.52	2.43
P.4	0.379	18.95	12.84	7.06	4.78	33.85	1.47	2.64
R.1.1	0.509	14.36	7.20	7.28	3.65	26.57	1.99	1.96
R.1.2	0.464	15.90	7.72	7.37	3.58	26.42	2.05	2.15
R.1.3	0.417	16.46	8.63	6.83	3.58	24.46	1.90	2.40
R.1.4	0.394	17.10	9.27	6.68	3.62	24.23	1.84	2.54
R.2.1	0.505	14.19	7.65	7.19	3.87	27.90	1.85	1.98
R.2.2	0.466	15.49	8.33	7.18	3.86	27.78	1.85	2.15
R.2.3	0.413	16.68	9.00	6.92	3.73	25.85	1.85	2.42
R.2.4	0.392	17.54	9.52	6.85	3.72	25.52	1.84	2.55
R.3.1	0.510	14.77	7.54	7.48	3.82	28.62	1.95	1.96
R.3.2	0.468	16.00	8.15	7.42	3.78	28.07	1.96	2.14
R.3.3	0.419	16.73	8.74	6.94	3.62	25.18	1.91	2.39
R.3.4	0.393	18.18	9.20	7.10	3.59	25.57	1.97	2.54

Table(8.6) The dimensional parameters of the fabrics after mercerization immediately after dry relaxation.

the "K_s" values increased by a very significant amount, (see Figures (7.1) to (7.5)).

ii) After mercerizing the "K_s" values of the fabrics were more variable than after the previous treatments, (see Figure 8.2).

It will be noted that after this treatment in both plain and rib structures there is a significant increase in "K_s" value with increase in stitch length, (i.e., fabrics which after washing and tumble drying gave clear evidence of a constant value of "K_s" independent of stitch length, now after the mercerizing treatment exhibited entirely different trends).

In contrast the interlock fabrics which after washing and tumble drying gave results clearly indicating that in this state of relaxation these "K_s" values were not constants but changed with change in stitch length, after mercerizing the "K_s" values were different but showed no evidence of any clear relationship with stitch length.

iii) The "K_s" values after the mercerizing treatment were much higher than after the previous relaxation treatments.

These results indicated that whereas after the caustic soda treatment very little change in fabric characteristics was to be observed, after mercerizing the effect on dimensions was most marked.

One obvious factor which may be responsible for these effects is the shrinkage of the yarns of the fabrics during the mercerizing treatment. This matter was investigated in more detail by unroving and measuring the samples which were treated in (C.S.+T.D.) and (M.+T.D.), in the same way as described previously for the fabrics in (W.M.+T.D.) relaxation treatment (see section VII.3). The new stitch length values were found and tabulated in Table(8.7). From this information, the "K_c", "K_w", "K_s" and "K_r" values for the fabrics in the caustic soda treatment and after mercerizing were obtained using the actual stitch length measured in the fabric after the treatment. These values are given in Tables (8.8) and (8.9) respectively. The new "K_s" values were plotted against the shrunk stitch length in Figure(8.9) and Figure(8.10).

iv) Statistical consideration of the form of the graphs of "K_s" against stitch length for all the structures after the G(C.S.+T.D.) treatment and the mercerizing treatment, using the shrunk stitch length, were undertaken in the same manner mentioned in the previous chapter. The results of the F-test and the statistical significance at the 5% and 1% levels are recorded in Table(8.10) and Table(8.11) respectively.

Sample	Stitch length Original state (cm.)	Stitch length Caustic soda (cm.)	Stitch length Mercerization (cm.)
I.1	0.436	0.426	0.362
I.2	0.385	0.378	0.322
I.3	0.357	0.353	0.302
I.4	0.335	0.328	0.286
P.1	0.541	0.512	0.428
P.2	0.463	0.442	0.381
P.3	0.411	0.399	0.355
P.4	0.379	0.370	0.330
R.1.1	0.509	0.497	0.418
R.1.2	0.464	0.453	0.385
R.1.3	0.417	0.405	0.347
R.1.4	0.394	0.381	0.333
R.2.1	0.505	0.487	0.408
R.2.2	0.466	0.449	0.377
R.2.3	0.413	0.401	0.342
R.2.4	0.392	0.379	0.328
R.3.1	0.510	0.493	0.412
R.3.2	0.468	0.451	0.382
R.3.3	0.419	0.404	0.346
R.3.4	0.393	0.382	0.332

Table(8.7) The stitch length at original state and after caustic soda and mercerizing treatments for all the fabrics.

(C.S.+T.D.) with "shrunk stitch length"

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.426	12.41	13.46	5.28	5.73	30.31	0.92	4.69
I.2	0.378	13.99	14.40	5.28	5.44	28.78	0.97	5.29
I.3	0.353	15.03	14.45	5.30	5.10	27.06	1.04	5.64
I.4	0.328	16.18	14.70	5.30	4.82	25.58	1.10	6.09
P.1	0.512	9.95	8.40	5.09	4.30	21.90	1.18	1.95
P.2	0.442	12.18	9.49	5.38	4.19	22.58	1.28	2.26
P.3	0.399	13.82	10.13	5.51	4.04	22.28	1.36	2.50
P.4	0.370	16.01	11.15	5.92	4.12	24.43	1.43	2.70
R.1.1	0.497	10.55	6.72	5.24	3.33	17.51	1.56	2.01
R.1.2	0.453	11.82	7.27	5.35	3.29	17.63	1.62	2.20
R.1.3	0.405	13.13	7.93	5.31	3.21	17.07	1.65	2.46
R.1.4	0.381	13.89	8.14	5.29	3.10	16.41	1.70	2.62
R.2.1	0.487	10.32	6.67	5.02	3.24	16.32	1.54	2.05
R.2.2	0.449	11.55	6.98	5.18	3.13	16.25	1.65	2.22
R.2.3	0.401	13.18	7.75	5.28	3.10	16.42	1.70	2.49
R.2.4	0.379	14.09	8.10	5.34	3.06	16.39	1.73	2.63
R.3.1	0.493	10.81	6.88	5.32	3.39	18.07	1.57	2.02
R.3.2	0.451	12.15	7.36	5.47	3.31	18.18	1.65	2.21
R.3.3	0.404	13.37	8.07	5.40	3.26	17.61	1.65	2.47
R.3.4	0.382	14.86	8.09	5.67	3.09	17.54	1.83	2.61

Table(8.8) The dimensional parameters of the fabrics after caustic soda treatment immediately after dry relaxation.

(M.+T.D.) with "shrunk stitch length"

Sample	ℓ/cm.	C.P.cm.	W.P.cm.	K_c	K_w	K_s	K_r	$1/\ell$
I.1	0.362	17.73	11.89	6.41	4.30	27.62	1.49	5.52
I.2	0.322	20.00	13.81	6.44	4.44	28.63	1.44	6.21
I.3	0.302	20.61	14.65	6.22	4.42	27.53	1.40	6.62
I.4	0.286	21.34	15.57	6.10	4.45	27.17	1.37	6.99
P.1	0.428	13.57	9.56	5.80	4.09	23.76	1.41	2.33
P.2	0.381	15.89	10.88	6.05	4.14	25.09	1.46	2.62
P.3	0.355	17.42	11.46	6.18	4.06	25.15	1.52	2.81
P.4	0.330	18.95	12.84	6.25	4.23	26.49	1.47	3.03
R.1.1	0.416	14.36	7.20	5.97	2.99	17.89	1.99	2.40
R.1.2	0.385	15.90	7.72	6.12	2.97	18.19	2.05	2.59
R.1.3	0.347	16.46	8.63	5.71	2.99	17.10	1.90	2.88
R.1.4	0.333	17.10	9.27	5.69	3.08	17.57	1.84	3.00
R.2.1	0.408	14.19	7.65	5.78	3.12	18.07	1.85	2.45
R.2.2	0.377	15.49	8.33	5.83	3.14	18.33	1.85	2.65
R.2.3	0.342	16.68	9.00	5.70	3.07	17.55	1.85	2.92
R.2.4	0.328	17.54	9.52	5.75	3.12	17.96	1.84	3.04
R.3.1	0.412	14.77	7.54	6.08	3.10	18.90	1.95	2.42
R.3.2	0.382	16.00	8.15	6.11	3.11	19.02	1.96	2.61
R.3.3	0.346	16.73	8.74	5.78	3.02	17.50	1.91	2.89
R.3.4	0.332	18.18	9.20	6.03	3.05	18.43	1.97	3.01

Table(8.9) The dimensional parameters of the fabrics after mercerization immediately after dry relaxation.

Structure / relaxation	Interlock	Plain	Rib (single)	Rib (2-fold)	Rib (2-ends)
G(C.S+T.D)	681.428	1.521	1.362	0.038	0.341
(M.+T.D.)	1.376	62.662	13.813	6.238	34.041

Table(8.10) The values of F-test for all fabrics.

Structure / relaxation	Interlock	Plain	Rib (single)	Rib (2-fold)	Rib (2-ends)
G(C.S+T.D)	1%	N.S.*	N.S.	N.S.	N.S.
(M.+T.D.)	N.S.	1%	1%	5%	1%

Table(8.11) Statistical significance of relating "K_s" with stitch length in comparison with horizontal line.

* non-significant

v) Discussion of statistical results:

It will be observed that after the caustic soda treatment in all cases apart from the interlock structure, there is no statistical significance to the slope of the "K_s" versus stitch length relationship. According to the previous arguments given in section VII.1.1.iv, this suggests that these structures are more completely relaxed after the caustic soda treatment than after any previous washing and tumble drying treatment. In contrast, the slope of the "K_s" versus stitch length interlock relationship is still clearly significantly different from zero.

On the contrary, after the mercerizing treatment, in the case of the interlock structure the variation of "K_s" value with stitch length was non-significant, whereas, in the case of the plain and rib structures, this variation was shown to be significant at the 1% level.

One could argue, therefore, that in the case of the interlock structure, for the first time, after mercerizing a "K_s" value independent of stitch length has been obtained, suggesting that if a constant "K_s" value is a sign of complete relaxation, this severe treatment is necessary in the case of cotton interlock fabric, to achieve it in a relaxed state. On the other hand, in the case of rib and plain structures, the mercerizing is sufficiently severe to produce a fabric which is no longer in a truly relaxed state.

vi) The "K_s" value after caustic soda and mercerizing treatments are shown in Table(8.12) for all structures. As can be observed from this Table, in the case of interlock and rib structures after the mercerizing treatment, the average value of "K_s", when calculated using the shrunk stitch length are not significantly different than that obtained after the washing and tumbling stage. In the case of the plain fabric the "K_s" value is greater than that for the washing and tumbling stage.

Structure / relaxation	Interlock	Plain	Rib (single)	Rib (2-fold)	Rib (2-ends)
G(C.S.+T.D)	29.8±2.4	24.8±0.5	18.4±0.1	18.1±0.2	19.7±0.4
(C.S.+T.D.)	28.9±2.5	24.3±0.5	17.9±0.6	17.6±0.1	18.8±0.4
(M.+T.D.) using shrunk (ℓ)	27.9±0.7	25.1±1.4	17.6±0.5	17.9±0.4	18.3±0.8

Table(8.12) The "K_s" value for all structures after the caustic soda and mercerizing treatments.

vii) As can be observed from the resultant "K_s" values for rib fabrics knitted from two-fold and single yarns, the average of these values, contrary to those after washing and tumble drying treatment, are similar to each other (i.e., 18 and 18.07 for two-fold and single yarns respectively, see Table(8.9)). This suggests that the difference in "K_s" values after washing and tumble drying for the fabrics knitted from yarns of different construction noted in section VII.3.2, is caused by incomplete relaxation and hence difference in loop shape at that stage, rather than any effect due to difference in yarn shrinkage. After the mercerizing treatment, the loop shape is equal for both constructions of yarns, because they are in their full compaction state and then the "K_s" value for both fabrics either knitted from two-fold or single yarns is the same.

VIII.2.1.2 "K_r" Values

i) From Figures (7.11) to (7.15) it is to be noted that whereas the "K_r" values increased slightly with increased relaxation compared with the wet relaxed figure, in all cases, after the mercerizing treatment, there is a significant increase in the value of "K_r". These results are summerized in Table(8.13) and Table(8.14). (This statistical consideration has been done by a statistical method which was devised in a computer program in Appendix(62)).

ii) The average "K_r" values for the sample fabrics after mercerizing and tumbling are also given in Table(8.14). It will be noted, that for all fabrics these "K_r" values are considerably greater than those previously given by Woolfardt, Knapton, Munden, Aziz, etc. for wool fabrics. This could imply that considerable distortion to the loop had occured as a result of the mercerizing treatment. Alternatively, it is possible to postulate that the treatment has caused the loop to take up a different natural configuration.

iii) In the case of plain and rib structures it will be recalled that the slope of the relationship between "K_r" value and stitch length, decreased with increase in the severity of the relaxation treatments. Even after the caustic soda treatment, (see Figures 8.5 and 8.7) this effect is still evident. After the mercerizing treatment,

Structure	Mean K_{r1}^{*}	Mean K_{r2}^{**}	V_1	V_2	S	t-test	Significant
interlock	0.99	1.02	0.004	0.005	0.066	0.942	N.S.
plain	1.33	1.34	0.011	0.007	0.094	0.461	N.S.
rib(single)	1.62	1.62	0.007	0.002	0.064	0.345	N.S.
rib(2-fold)	1.67	1.64	0.008	0.003	0.072	0.798	N.S.
rib(2-ends)	1.61	1.63	0.026	0.006	0.127	0.271	N.S.

Table(8.13) Comparison of "K_r" values after G(W.M.+T.D.) and (W.R.) treatments.

Structure	Mean K_{r1}	Mean K_{r3}^{***}	V_1	V_2	S	t-test	Significant
interlock	0.99	1.49	0.004	0.003	0.057	21.23	1%
plain	1.33	1.51	0.011	0.000	0.075	5.97	1%
rib(single)	1.62	1.94	0.007	0.003	0.070	11.25	1%
rib(2-fold)	1.67	1.92	0.008	0.002	0.078	7.87	1%
rib(2-ends)	1.61	1.94	0.026	0.001	0.118	6.86	1%

Table(8.14) Comparison of "K_r" values after G(M.+T.D.) and (W.R.) treatments.

* K_{r1} value of K_r after wet relaxation

** K_{r2} value of K_r after washing and tumble drying

*** K_{r3} value of K_r after mercerizing and tumble drying however, (see Figures 8.6 and 8.8) almost horizontal lines was obtained for this relationship indicating that after this treatment the "K_r" value is independent of the value of stitch length. If this is considered as the state of complete relaxation then relaxation of these structures only occurs after the mercerizing treatment.

The general concept of the geometry of the knitted loop, was based on the assumption, that the relaxed shape of a uniform loops of a homogeneous material was independent of the length of the loop and the material from which it was made[10].

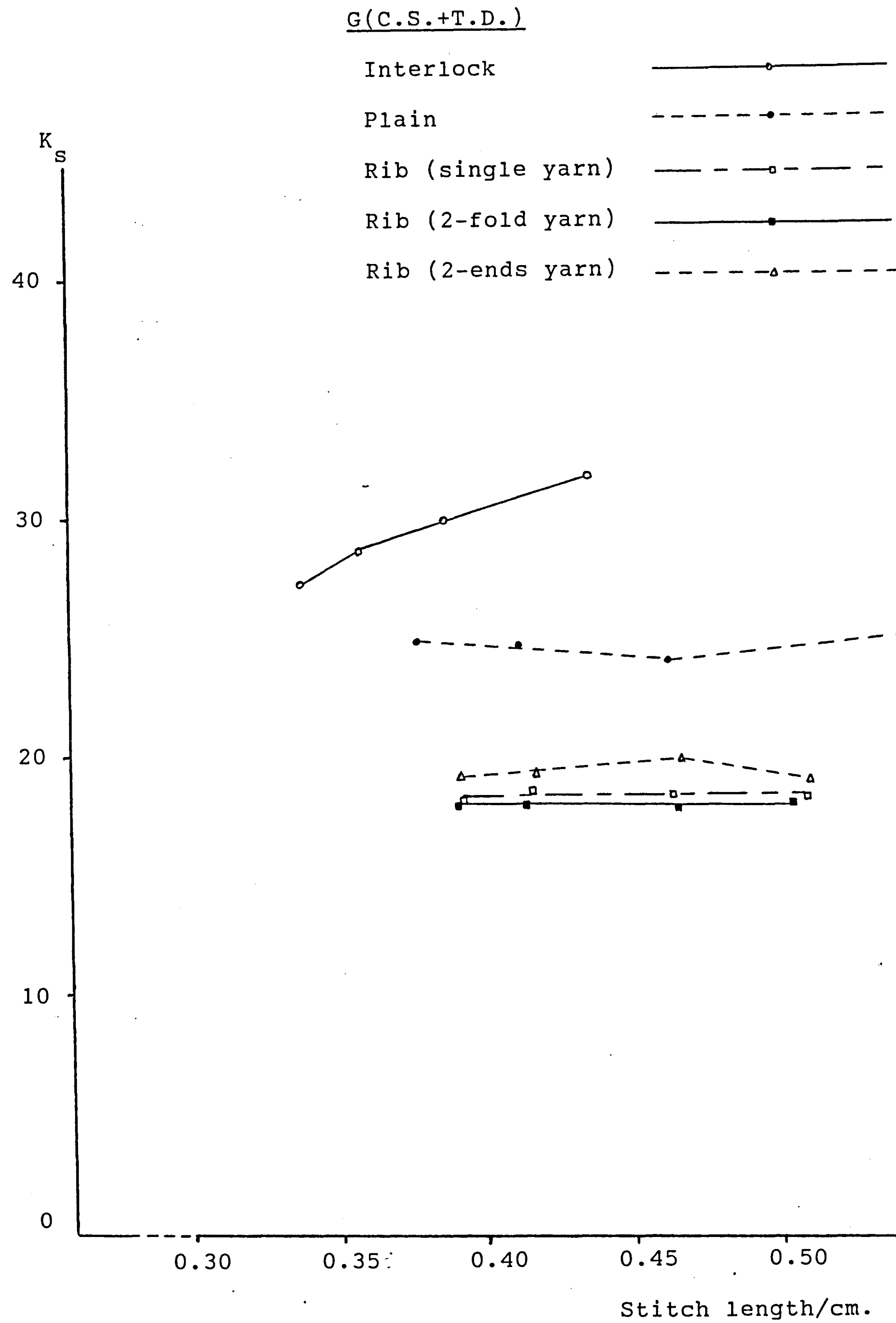
It is thus very reasonable to argue that a "K_r" value (a measure of the width to length ratio of the knitted loop) is the most sensitive way of detecting whether the fabric structure approximates to a relaxed state, which will only occur if "K_r" is a constant independent of stitch length. This line of reasoning suggests that in the case of the plain and rib cotton fabrics, the mercerizing treatment has brought these structures, most nearly to a relaxed state, despite the fact that after this treatment, there is some evidence of a small change in "K_s" value with change in stitch length.

iv) In the case of interlock it has previously been noted that there is a very marked slope in the relationship between "K_r" and stitch length and this remains after the G(C.S.+T.D.) treatment. However after the mercerizing treatment the slope of the relationship is reversed, i.e., for an increase in stitch length the "K_r" value increases.

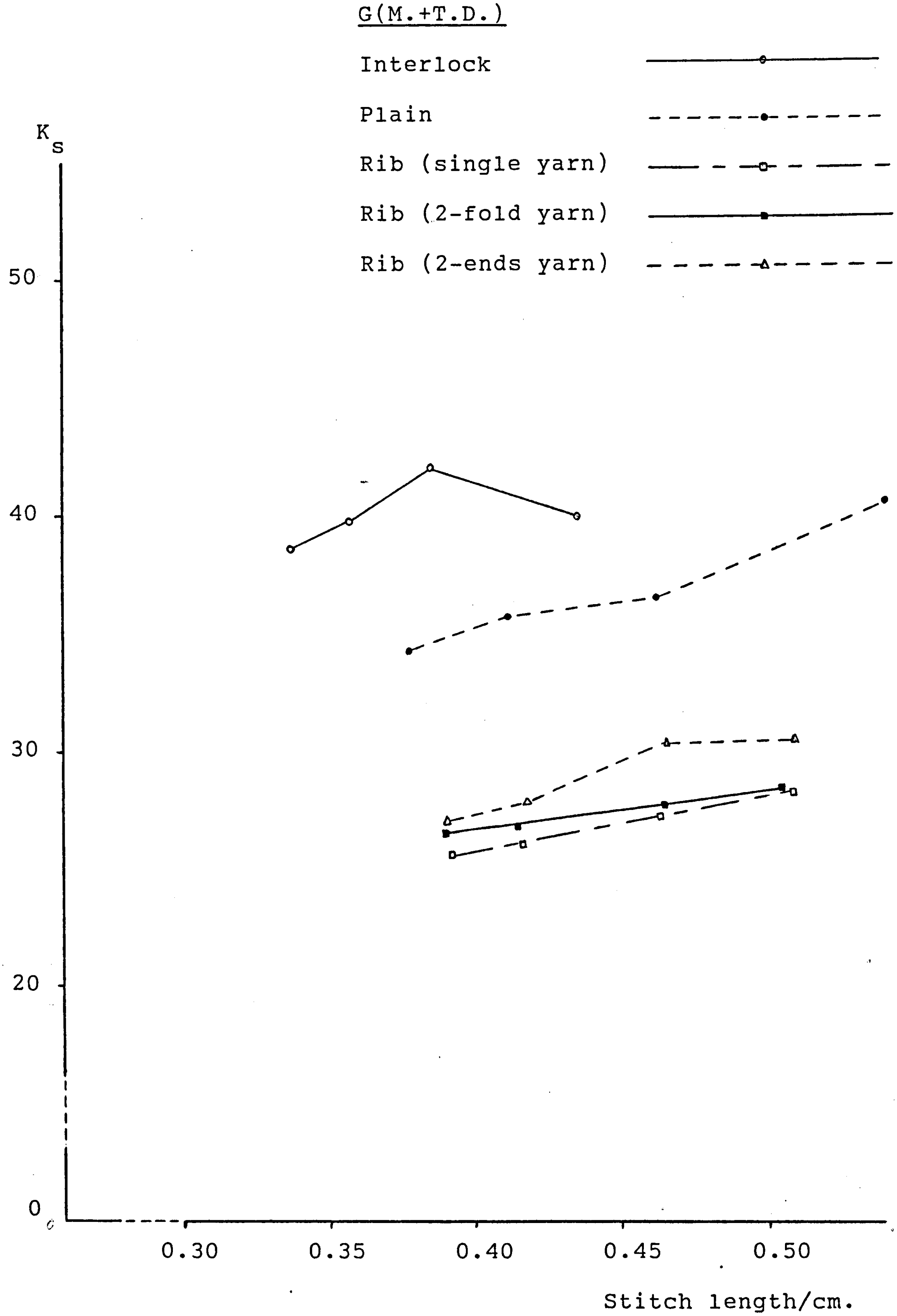
This relationship is unexpected and not previously observed, and is certainly worthy of further investigation.

A possible cause might be linked with the rigidity of the interlock structure particularly after mercerizing. During mercerization the stitch length of the structure decreases, so that the fabric structure has to decrease in area. The width of the fabric, however, is largely determined by the yarn diameter, so that most of the fabric shrinkage caused by the yarn shrinkage has to take place in the length direction. In the case of the slackly knitted fabrics, where the yarn shrinkage is greater, thus would suggest a large decrease in the length direction causing a greater increase in the "K_r" value than would apply to the more tightly knitted structures where the yarn shrinkage is less. With this explanation, therefore, one would expect, as observed experimentally, that the slacker fabric would takes up a final configuration with a higher "K_r" value.

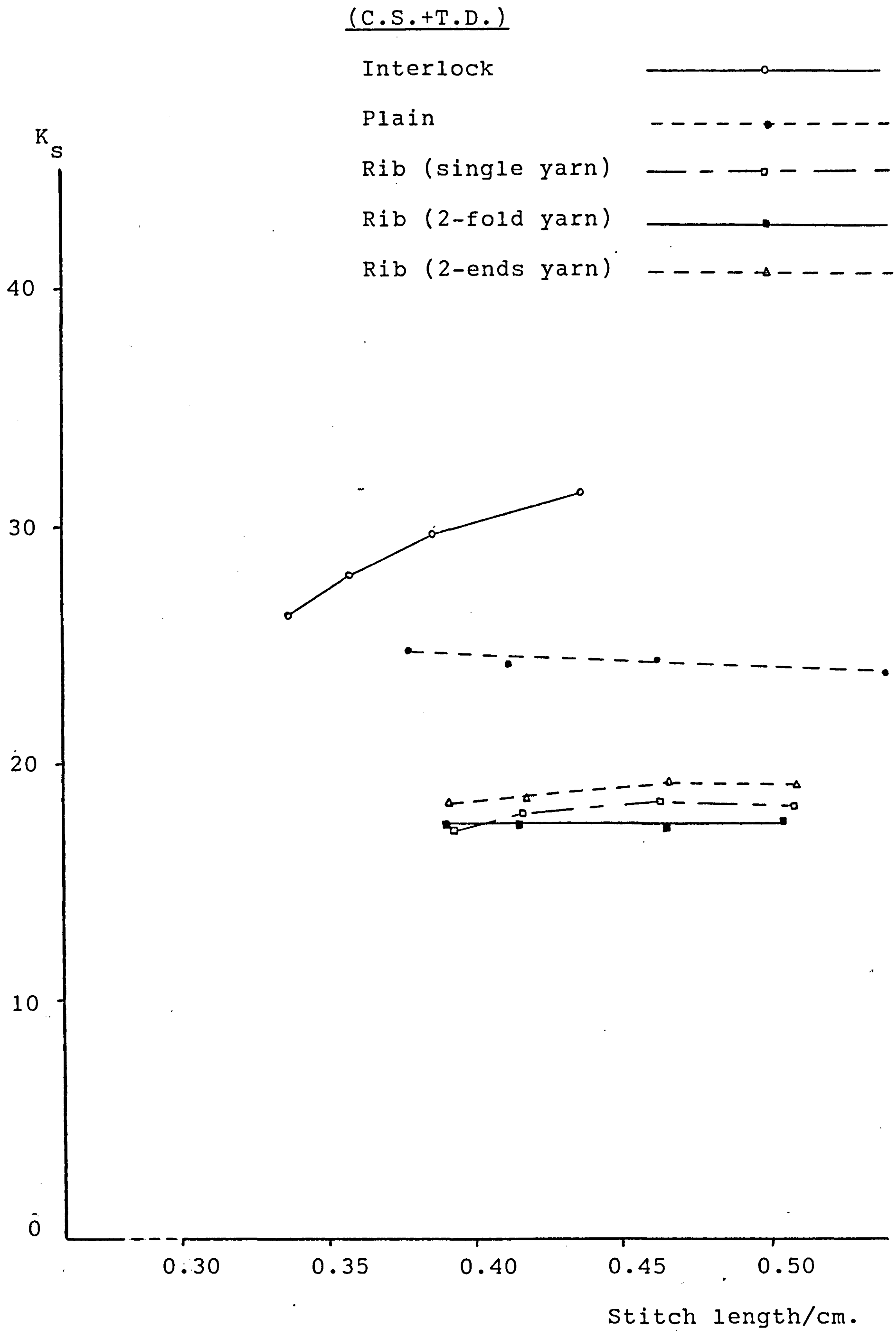
This problem is not so critically encountered in the case of plain and rib fabrics since they are much more loosely constructed compared with the interlock fabrics.



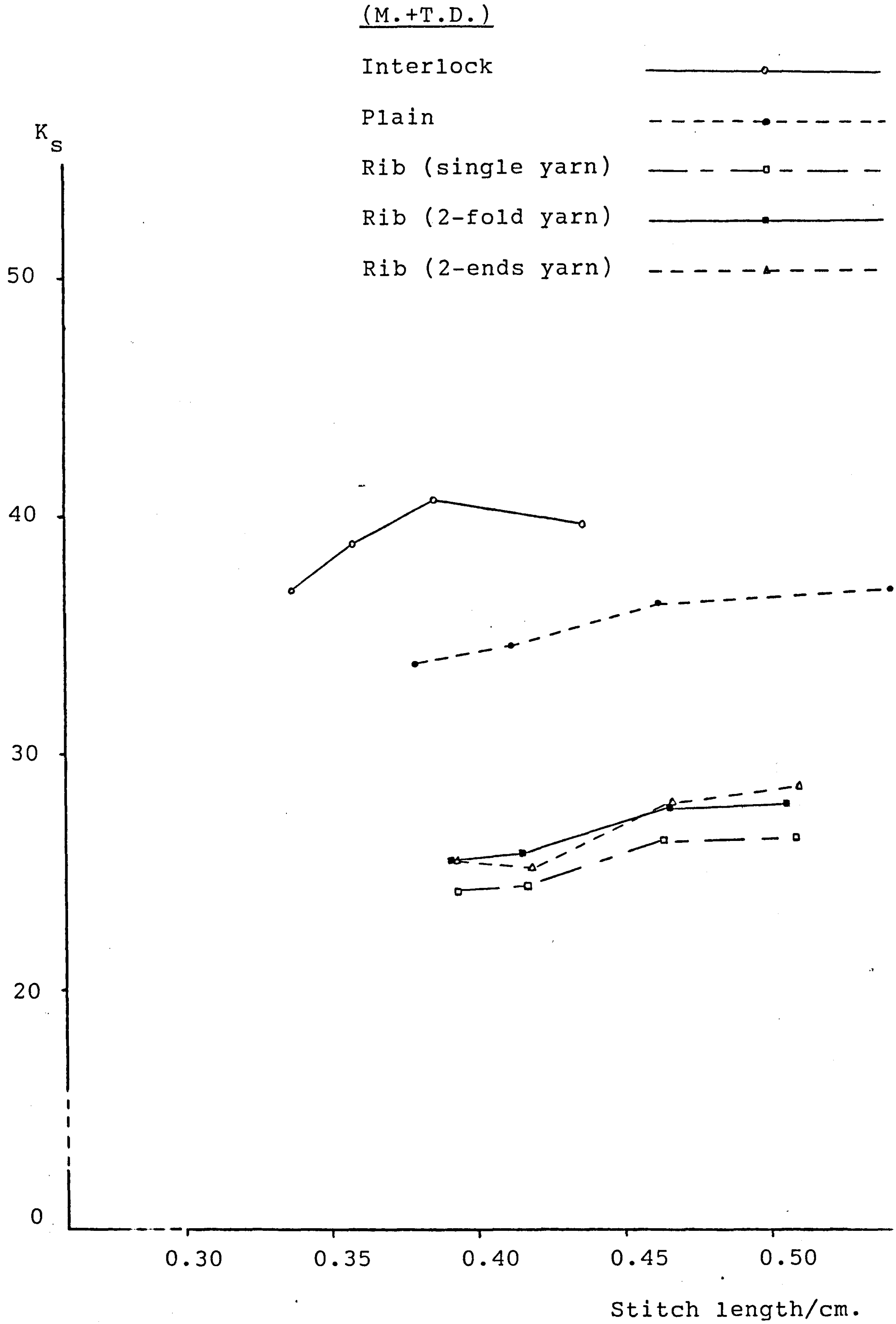
Figure(8.1) "K_s" values versus stitch length.



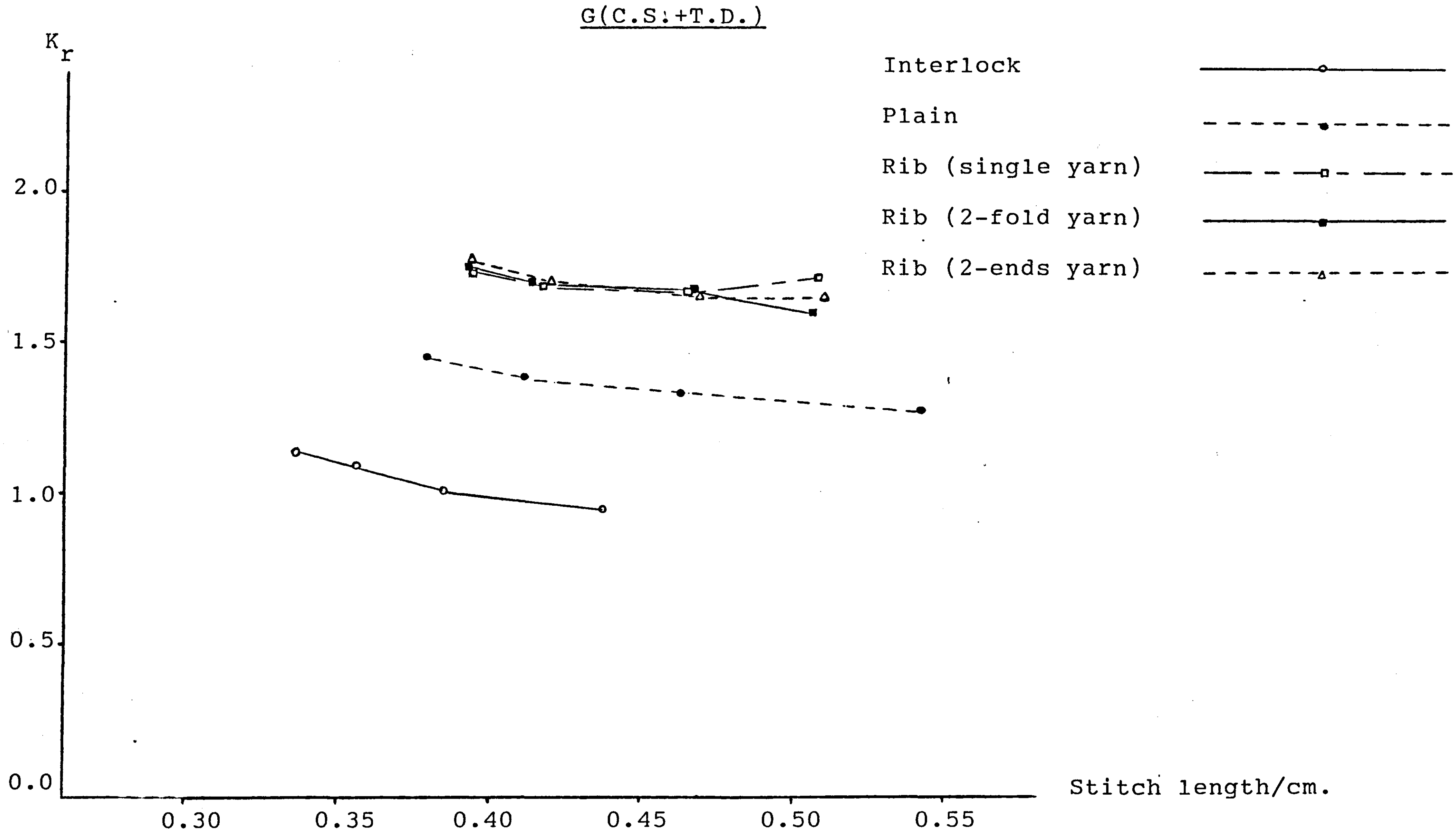
Figure(8.2) "K_s" values versus stitch length.



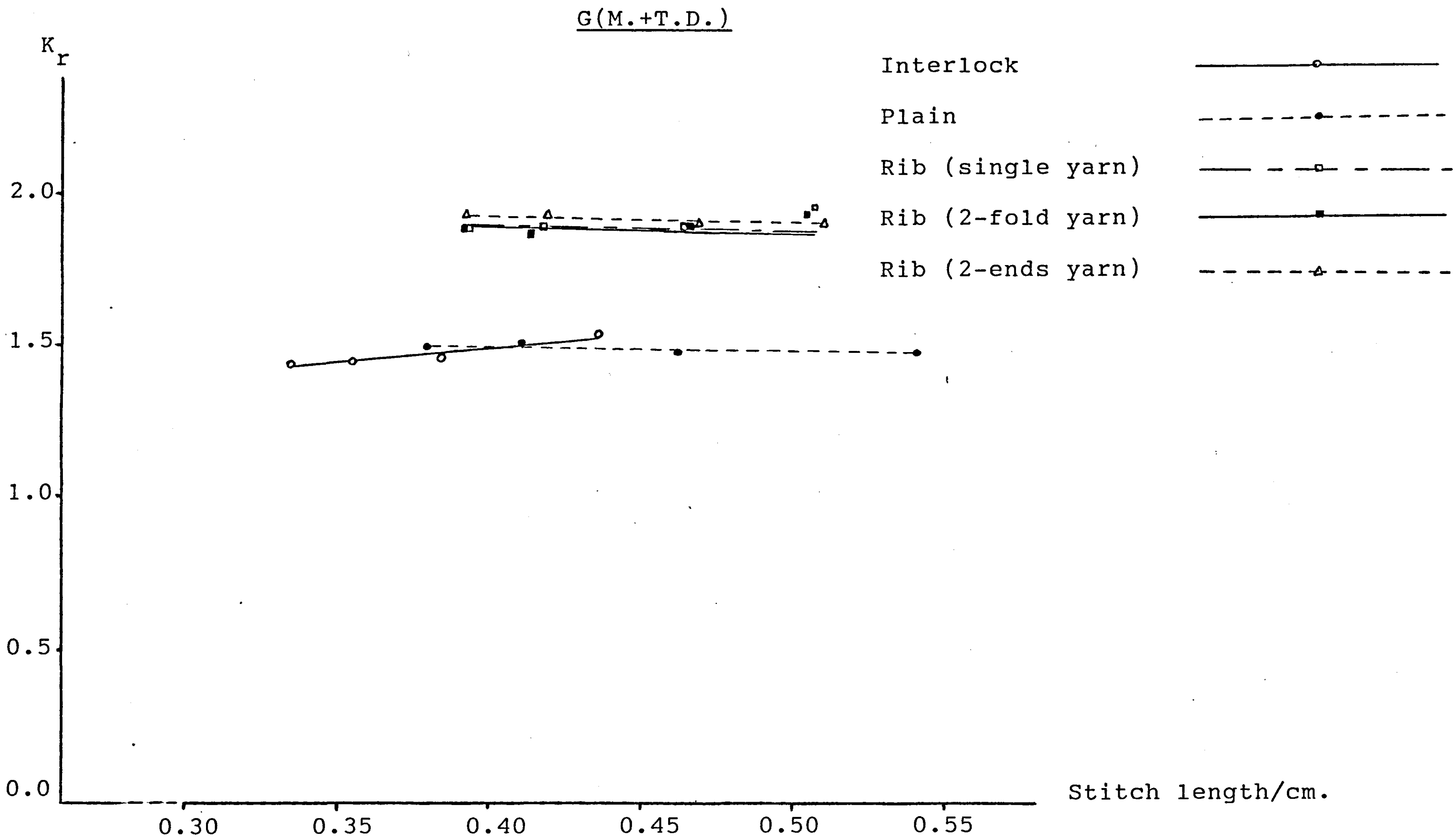
Figure(8.3) "K_s" values versus stitch length.



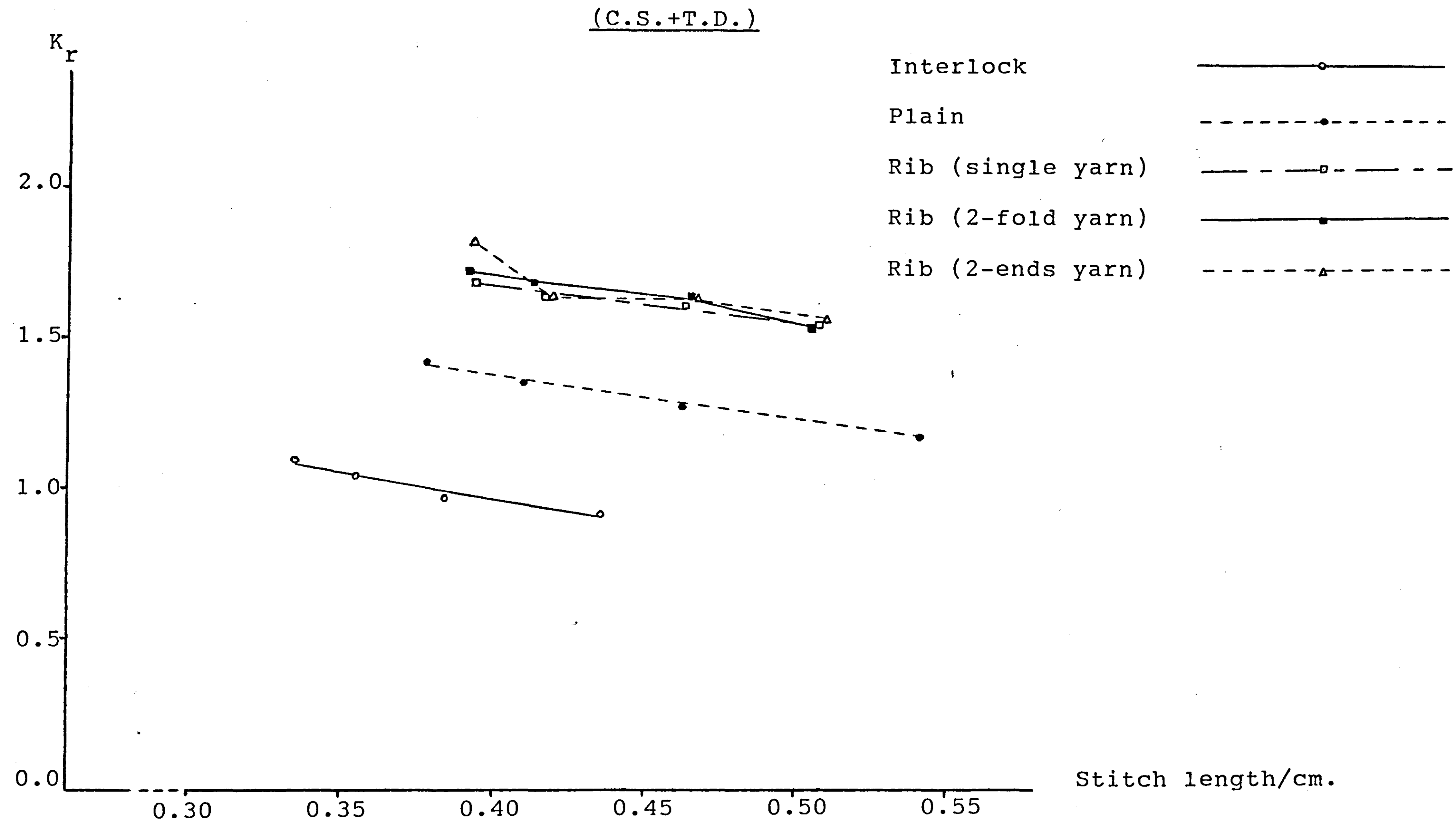
Figure(8.4) "K_s" values versus stitch length.



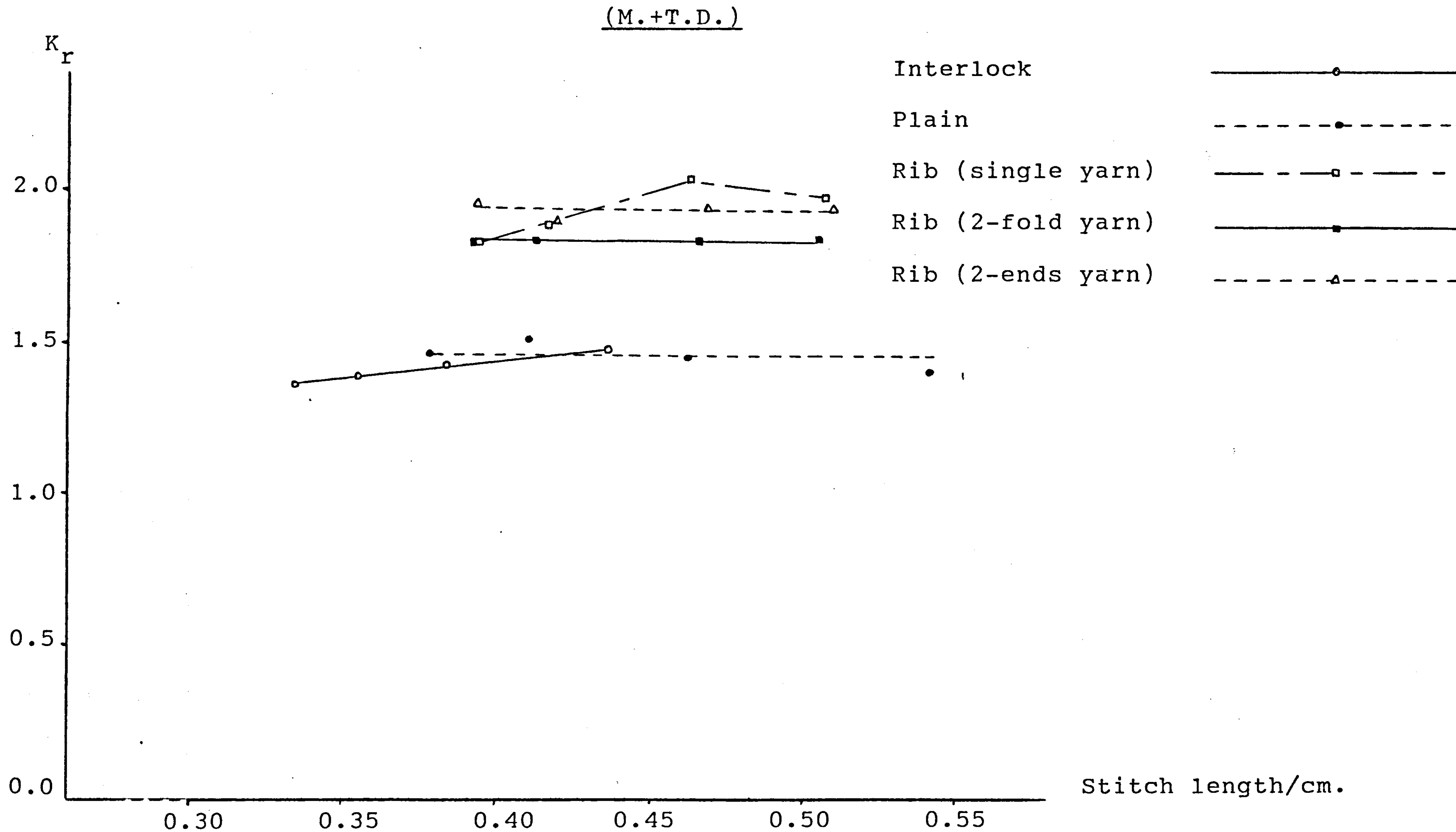
Figure(8.5) "K_r" values versus stitch length.



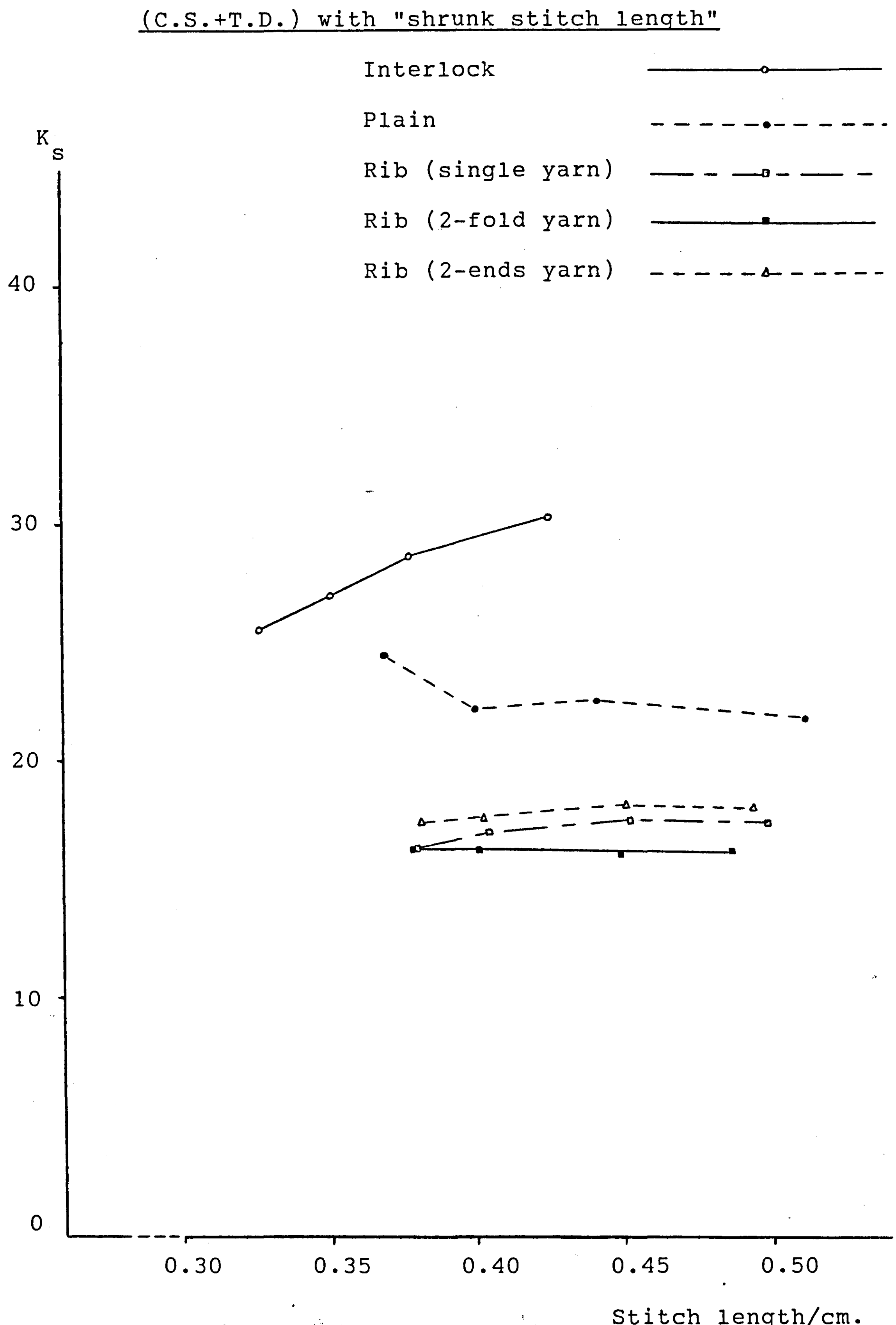
Figure(8.6) "K_r" values versus stitch length.



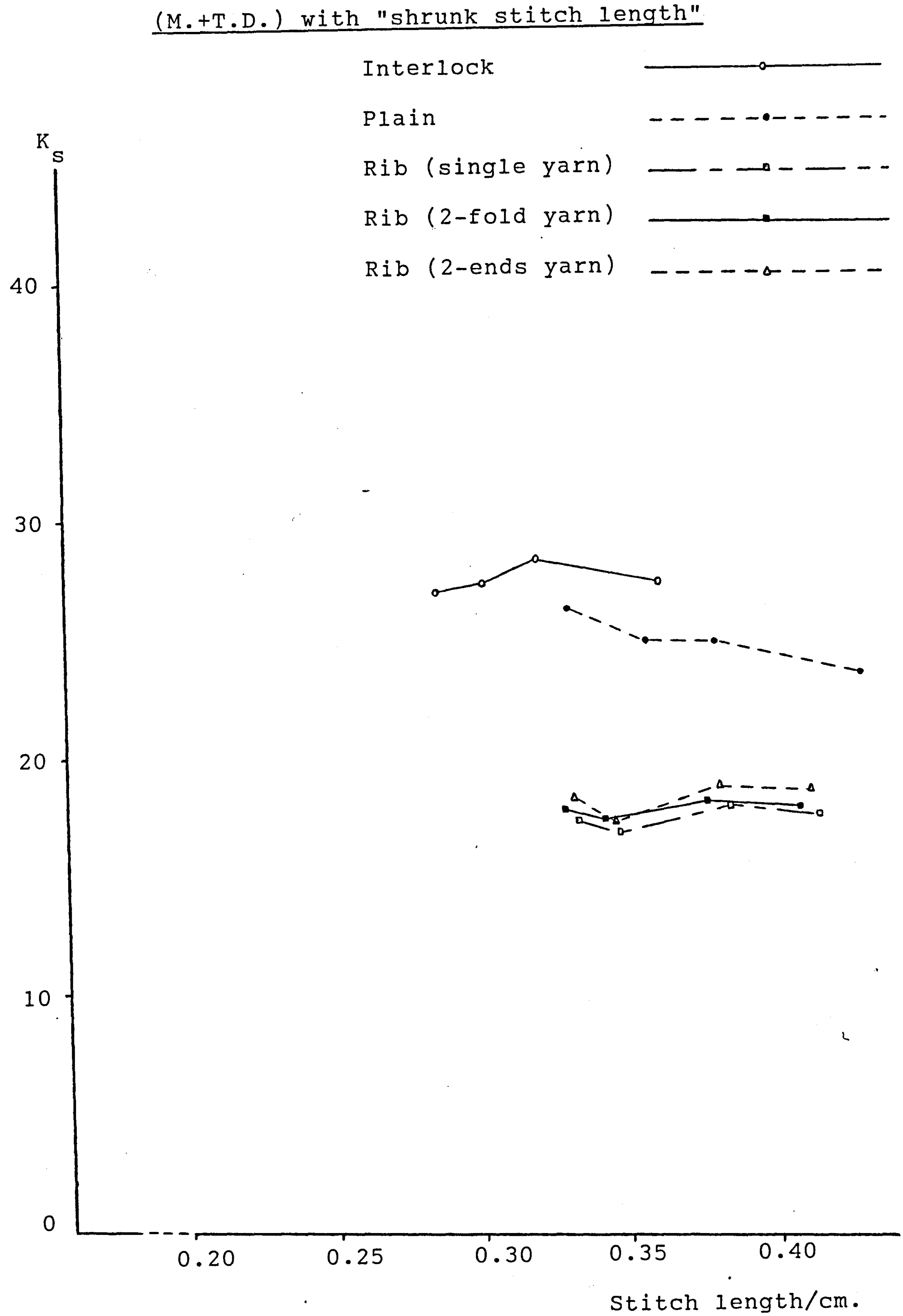
Figure(8.7) "K_r" values versus stitch length.



Figure(8.8) "K_r" values versus stitch length.



Figure(8.9) "K_s" values versus shrunk stitch length.



Figure(8.10) "K_s" values versus shrunk stitch length.

VIII.3 The Effect Of Mercerizing On The Area Shrinkage

The widths and lengths of all samples have been measured in the G(C.S.+T.D.), G(M.+T.D.), (C.S.+T.D.) and (M.+T.D.) treatments and recorded in appendices 38 to 49. The percentage area shrinkage of each sample was, then, calculated and listed in Tables (8.15) to (8.18). The results show that (see Figures (7.21) to (7.25)), the mercerizing treatment produces a much greater area shrinkage on the fabrics than all previous relaxation treatments, because in this treatment the length of the yarn shrinks thus causing the fabric to decrease in dimensions. The figures for area shrinkage of the different structures, in this stage of relaxation, are given in Table(8.19).

It is interesting to compare the area shrinkages given in Table(8.19) with those obtained on the same fabrics after washing and tumble drying (see Table 7.18).

Thus, whereas after mercerization all the fabric structures show similar degrees of shrinkage, after washing and tumbling, the plain fabric structure was much lower than that obtained for the other structures.

G(C.S.+T.D.)

Sample	Length (cm.)	Width (cm.)	Area (cm^2)	Area shrinkage ($cm.^2$)	Area shrinkage percentage
I.1	16.5	25.2	415.8	209.2	33.47%
I.2	16.8	23.6	396.5	228.5	36.56%
I.3	17.4	23.1	401.9	223.1	35.68%
I.4	17.5	23.2	406.0	219.0	35.04%
P.1	17.8	26.0	462.8	162.2	25.95%
P.2	19.3	24.0	463.2	161.8	25.88%
P.3	19.8	22.5	445.5	179.5	28.72%
P.4	22.9	20.6	471.7	153.3	24.52%
R.1.1	17.1	27.8	475.4	149.6	23.93%
R.1.2	18.3	24.4	446.5	178.5	28.55%
R.1.3	19.2	22.1	424.3	200.7	32.10%
R.1.4	20.0	20.8	416.0	209.0	33.44%
R.2.1	18.0	23.7	426.6	198.4	31.74%
R.2.2	18.8	22.1	415.5	209.5	33.52%
R.2.3	19.6	21.3	417.5	207.5	33.20%
R.2.4	20.2	20.5	414.1	210.9	33.74%
R.3.1	17.3	27.9	482.7	142.3	22.77%
R.3.2	18.6	24.1	448.3	176.7	28.27%
R.3.3	19.1	21.8	416.4	208.6	33.37%
R.3.4	20.6	19.9	409.9	215.1	34.40%

Table(8.15) The fabrics' dimensions after caustic soda treatment.

G(M.+T.D.)

Sample	Length (cm.)	Width (cm.)	Area ($cm.^2$)	Area shrinkage ($cm.^2$)	Area shrinkage percentage
I.1	11.6	28.8	334.1	290.9	46.54%
I.2	11.8	24.1	284.4	340.6	54.49%
I.3	12.8	22.8	291.8	333.2	53.30%
I.4	13.1	22.0	288.2	336.8	53.88%
P.1	13.0	22.1	287.3	337.7	54.03%
P.2	14.9	20.6	306.9	318.1	50.88%
P.3	15.8	19.6	309.7	315.3	50.45%
P.4	19.3	17.9	345.5	279.5	44.72%
R.1.1	12.8	24.4	312.3	312.7	50.02%
R.1.2	14.2	21.4	303.9	321.1	51.37%
R.1.3	15.3	19.8	302.9	322.1	51.52%
R.1.4	16.2	18.4	298.1	326.9	52.30%
R.2.1	13.0	21.1	274.3	350.7	56.11%
R.2.2	14.3	18.8	268.8	356.2	56.98%
R.2.3	15.4	18.4	283.4	341.6	54.66%
R.2.4	16.1	17.6	283.4	341.6	54.66%
R.3.1	12.8	23.8	304.6	320.4	51.25%
R.3.2	14.1	21.1	297.5	327.5	52.39%
R.3.3	15.0	19.5	292.5	332.5	53.20%
R.3.4	16.6	17.6	292.2	332.8	53.25%

Table(8.16) The fabrics' dimensions after mercerization.

(C.S.+T.D.)

Sample	Length (cm.)	Width (cm.)	Area (cm^2)	Area shrinkage ($cm.^2$)	Area shrinkage percentage
I.1	17.0	25.0	425.0	200.0	32.00%
I.2	17.3	23.3	403.1	221.9	35.50%
I.3	18.1	22.9	414.5	210.5	33.68%
I.4	18.2	23.2	422.2	202.8	32.44%
P.1	19.1	25.7	490.9	134.1	21.46%
P.2	19.7	23.4	461.0	164.0	26.24%
P.3	20.3	22.5	456.7	168.3	26.92%
P.4	23.2	20.5	475.6	149.4	23.90%
R.1.1	18.1	26.8	485.1	139.9	22.38%
R.1.2	18.7	24.0	448.8	176.2	28.19%
R.1.3	19.8	22.2	439.6	185.4	29.67%
R.1.4	20.8	21.2	441.0	184.0	29.44%
R.2.1	18.7	23.6	441.3	183.7	29.38%
R.2.2	19.4	22.2	430.7	194.3	31.09%
R.2.3	20.0	21.6	432.0	193.0	30.88%
R.2.4	20.8	20.8	432.6	192.4	30.77%
R.3.1	17.9	27.2	486.9	138.1	22.09%
R.3.2	19.1	24.6	469.9	155.1	24.82%
R.3.3	19.9	22.0	437.8	187.2	29.95%
R.3.4	20.8	20,7	430.6	194.4	31.11%

Table(8.17) The fabrics' dimensions after caustic soda treatment immediately after dry relaxation.

(M.+T.D.)

Sample	Length (cm.)	Width (cm.)	Area ($cm.^2$)	Area shrinkage ($cm.^2$)	Area shrinkage percentage
I.1	11.9	28.3	336.8	288.2	46.11%
I.2	12.1	24.3	294.0	331.0	52.95%
I.3	13.2	22.6	298.3	326.7	52.26%
I.4	13.8	21.9	302.2	322.8	51.64%
P.1	14.0	22.6	316.4	308.6	49.37%
P.2	15.1	20.4	308.0	317.0	50.71%
P.3	16.1	19.9	320.4	304.6	48.73%
P.4	19.6	17.8	348.9	276.1	44.17%
R.1.1	13.3	25.0	332.5	292.5	46.80%
R.1.2	13.9	22.6	314.1	310.9	49.73%
R.1.3	15.8	20.4	322.3	302.7	48.42%
R.1.4	16.9	18.6	314.3	310.7	49.70%
R.2.1	13.6	20.6	280.2	344.8	55.17%
R.2.2	14.5	18.6	269.7	355.3	56.84%
R.2.3	15.8	18.6	293.9	331.1	52.97%
R.2.4	16.7	17.7	295.6	329.4	52.70%
R.3.1	13.1	24.8	324.9	300.1	48.01%
R.3.2	14.5	22.2	321.9	303.1	48.49%
R.3.3	15.9	20.3	322.8	302.2	48.35%
R.3.4	17.0	18.2	309.4	315.7	50.49%

Table(8.18) The fabrics' dimensions after mercerization immediately after dry relaxation.

Structure	Area shrinkage percentage
interlock	51%
plain	48%
rib (single yarn)	48%
rib (2-fold yarn)	54%
rib (2-ends yarn)	49%

Table(8.19) The figures of area shrinkage for different cotton structures after mercerizing treatment.

CHAPTER IX

FURTHER STUDIES TO EXPLAIN THE DIFFERENCE IN "K_s" VALUES AFTER WASHING AND TUMBLE DRYING BETWEEN FABRICS KNITTED FROM YARNS OF DIFFERENT FIBRES

IX.1 Proposed Explanation Of "K_s" Values Of Fabrics After Washing And Tumble Drying Relaxation Treatments

From the investigations described in the previous chapters, it has been shown that the "K_s" values of cotton knitted fabrics, in different relaxation treatments (mechanical and chemical treatments), are different from those appropriate to wool knitted fabrics. Comparing the results obtained in this work for "K_s" values of cotton fabrics in different relaxation (see previous chapters Tables (7.1) to (7.6) and Tables (8.3) and (8.9)) with the "K_s" values of wool fabrics which were obtained by previous workers[12, 11, 17, 15, 19, 57, 39], it will be seen that the differences, in "K_s" values, increase after the fabrics have been tumbled. For instance, for fully relaxed wool interlock fabrics, before felting K_s= 25.2 and fully consolidated cotton interlock fabrics K_s= 28.2, this difference is considerable.

The more immediate explanation of this difference is to suggest that in this state of relaxation, the wool yarn takes up a different natural loop configuration from that of the cotton. If this were true, it would be the only relaxed state where this difference in loop shape occurs.

An alternative suggestion is that previously proposed by Munden[61] that after tumbling, the fabric is not obtained in a strain free state, but in an unnatural compressed configuration as a result of the compression forces acting on the fabric during the tumbling action. If this proposal is the true explanation, then the degree of compression posible will be related to the space available within the fabric structure, for the necessary decrease in dimensions to occur. Thus, fabrics of the same tightness factor knitted from wool and cotton would differ in the space available for contraction due to the difference in specific density of the two fibres.

The density of fibre is defined as follow:

$$\text{density of fibres} = \frac{\text{weight of fibres}}{\text{volume of fibres}}$$

From the above relationship and the densities of the wool and cotton fibres[62] (non-medullated wool= 1.31 gram/cm^3., scoured cotton= 1.55 gram/cm^3. and mercerized cotton= 1.54 gram/cm^3.) it is obvious that the wool fibres occupy more space in the yarn than cotton fibres. In the tumbling treatment, therefore, there is less space for the wool fibres to compact to each other. Thus, the wool fibres occupy more space than the cotton fibres due to their lower density and hence, the fabric shrinkage for wool fabric in completely contracted condition will be less than cotton fabric, thus suggesting a "K_s" value for cotton fabrics after washing and tumble drying greater than for wool fabrics.

This argument only applies to the dimensions after tumbling, since only during the tumbling treatment is any compressional force exerted on the fabric. Thus, for dry and wet relaxation, differences in "K_s" values would be likely to be small, since in these conditions the natural shape of the wool and cotton loops should be the same.

IX.2 Relationship Between "K_s" Values And Fibre Densities

The following analyses quantitatively considers the effect of fibre density on the "K_s" value of fabrics after a compression treatment.

IX.2.1 The Effect Of Fibre Density On "K_s" values using the cover factor definitions

The cover factor relationship as defined by Munden[63] (as shown in Figure(9.1)) is as follows:

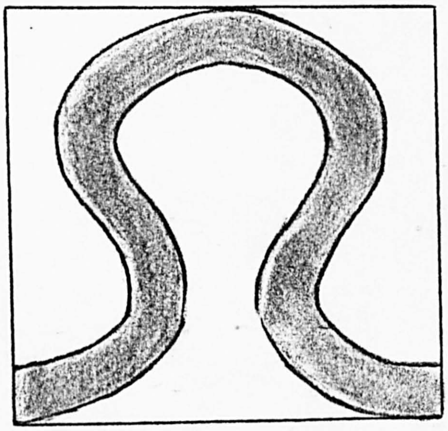
$$C = \frac{\ell . d}{\frac{1}{S}} = S.\ell.d = \frac{d.K_s}{\ell} \qquad (1)$$

where C= cover factor

ℓ= stitch length

d= yarn diameter

S= stitch density



Figure(9.1)

The following relationship, also, can be defined for yarn density:

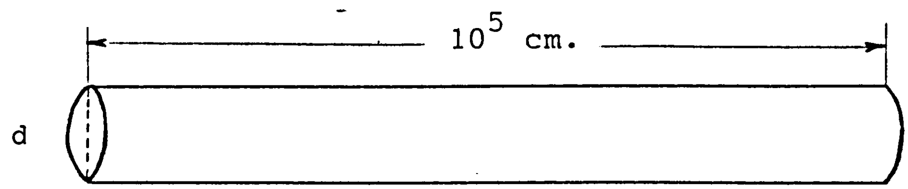
$$\text{yarn density} = \frac{\text{weight of yarn}}{\text{volume of yarn}}$$

From Figure(9.2) and using the yarn Tex count:

$$\rho = \frac{T}{\frac{\pi . d^2}{4} . \ell} \qquad (2)$$

where T= Tex (gram)

$\ell = 10^5$ cm.



Figure(9.2)

Therefore:

$$d = \sqrt{\frac{4T}{10^5 \pi . \rho}}$$

Then:

$$C = \frac{2K_s . \sqrt{T}}{\sqrt{10^5 \pi} . \sqrt{\rho} . \ell} = \frac{2K_s . K}{\sqrt{10^5 \pi} . \sqrt{\rho}}$$

where K= tightness factor $= \frac{\sqrt{T}}{\ell}$

Thus:

$$K_s = \frac{C . \sqrt{10^5 \pi} . \sqrt{\rho}}{2K} \qquad (3)$$

Now, for two fabrics knitted from two yarns having different value of "ρ"

$$K_{s1} = \frac{C_1 \cdot \sqrt{10^5 \pi} \cdot \sqrt{\rho_1}}{2K_1}$$

$$K_{s2} = \frac{C_2 \cdot \sqrt{10^5 \pi} \cdot \sqrt{\rho_2}}{2K_2}$$

$$\frac{K_{s1}}{K_{s2}} = \frac{C_1}{C_2} \cdot \frac{K_2}{K_1} \cdot \frac{\sqrt{\rho_1}}{\sqrt{\rho_2}} \qquad (4)$$

Thus, for two fabrics having the same cover factor (i.e., $\frac{C_1}{C_2} = 1$) and if these fabrics are knitted with yarns of same Tex and same stitch length, then:

$$\frac{K_{s1}}{K_{s2}} = \frac{\sqrt{\rho_1}}{\sqrt{\rho_2}} \qquad (5)$$

Table(9.1) compares the experimental and theoretical values of "K_s" values of different cotton fabric structures by using the above formula and the "K_s" values of wool fabrics, in full relaxation before felting, which were found by previous workers.

As can be observed from these results, in the case of plain fabrics, the theoretical value of "K_s" differs significantly from the experimental value after washing and tumbling treatment. This confirms that (as mentioned in previous chapters), in this stage of relaxation the plain cotton fabric has not achieved its fully contracted condition, whereas, after mercerization the obtained experimental value of "K_s" is in very good agreement with the calculated "K_s" value, i.e., mercerizing treatment causes a fully contracted state in plain cotton fabric.

Structure	K_s value of wool fabric	K_s value of cotton fabric		
		theoretical	experimental	
			G(W.M.+T.D.)	(M.+T.D.)
interlock	25.2	27.41	28.2	27.9
plain	23.6	25.59	23.9	25.1
rib	16.9	18.38	18.5	17.7

Table(9.1) The "K_s" values of wool and cotton fabrics after full relaxation treatments.

By using the accurate cover factor definition as follows:

$$C = \frac{\ell . d - 4d^2}{\frac{1}{S}} = \frac{d.K_s}{\ell} \left(1 - \frac{4d}{\ell}\right) \qquad (6)$$

the following equation will be obtained:

$$\frac{K_{s1}}{K_{s2}} = \frac{\rho_1}{\rho_2} \cdot \frac{\sqrt{\rho_2} - 0.0143K_2}{\sqrt{\rho_1} - 0.0143K_1} \qquad (7)$$

The "K_s" values for different cotton fabrics were calculated by Equation(7) (for normal K=14.5) as follows:

interlock	26.93
plain	25.22
rib	18.06

IX.3 Measurement Of Air Permeability And Its Relationship To Cover Factor

IX.3.1 Introduction

Thus the above analysis suggests that the difference between the "K_s" values of wool and cotton fabrics after tumble treatment can be explained in terms of the fabrics being compressed to an equivalent fibre cover.

The justification for this proposal, can best be established if an experimental verification of the fibre cover can be made. The measurement of air permeability offers such a method of fibre cover assessment.

IX.3.2 Analysis Of The Theoretical Flow Of Air Through A Fabric

The flow of air through a textile fabric can be seen to be a similar phenomenon to that of flow of air through a plate orifice.

Standard derivation of the equation of flow, through such an air space[64] shows that based on the general Bernoulli equation in compressible flow, viz. ,

$$\frac{v^2}{2} + \int \frac{dp}{\rho} = \text{constant} \qquad (8)$$

where v= the speed of fluid across the section of tube

p= the pressure of fluid across the section of tube

ρ= the density of the fluid.

the flow of air in the case of incompressible fluid through a contraction is given by:

$$q = \gamma a_2 \sqrt{\left[\frac{2\rho(p_1 - p_2)}{1 - m^2}\right]} \tag{9}$$

where q= the theoretical mass of air flowing per second

ρ= the density of the air (assuming that equals $1.225\ kg./m^{-3}$)

$(p_1 - p_2)$= the pressure drop across the plate

$m = \frac{a_2}{a_1}$

a_2= the area of the orifice

a_1= the area of the cross section of the tube

γ = the discharge coefficient of the orifice for incompressible flow.

When measuring the air flow through textile fabrics using the wind tunnel method described in Chapter V, the following facts apply:

a_1= the area of fabric

a_2= the area which is not covered by yarns

$$m = \frac{a_2}{a_1} = (1 - C.F.)$$

Thus, the Equation (9) becomes,

$$q \propto \frac{(1 - C.F.)}{\sqrt{1 - (1 - C.F.)^2}} \tag{10}$$

Hence,

$$\text{air permeability or air velocity} \propto \frac{(1 - C.F.)}{\sqrt{1 - (1 - C.F.)^2}}$$

Thus, the theoretical analysis suggests that the air permeability of the knitted fabric samples should be proportional to $\dfrac{(1 - C.F.)}{\sqrt{I - (1 - C.F.)^2}}$

The measurement of air permeability is, therefore, an independent method for checking the cover factor of the sample fabrics, and to this end it was decided to measure the air permeability of the plain knitted cotton fabrics which are listed in Table(6.1), after dry relaxed, wet relaxed, washing machine and tumble drying treatment, mercerizing and tumble drying treatment.

IX.3.3 Definitions

Definition of the terms used[55]:

i) Air Permeability:

The air permeability of a fabric is the volume of air measured in cubic centimetres passing per second through 1 cm^2. of the fabric at a pressure of 1 cm. of water.

ii) Air Resistance:

The air resistance of a fabric is the time in seconds for 1 cm^3. of air to pass through 1 cm^2. of the fabric under a pressure head of 1 cm. of water.

From the definitions above it will be realised that air resistance is the reciprocal of air permeability. The advantage in using air resistance values in preference to air permeability values lies in the fact that when a number of fabrics are superimposed to form a multi-layer assembly, the total air resistance is merely the sum of the individual values.

iii) Air Porosity:

This term is used in some papers on fabric properties and has the same meaning as air permeability.

Skinkle[55], however, suggested that the porosity of a fabric is the ratio of air space to the total volume of the fabric expressed as a percentage. This is a calculated value based on an estimation of the volume of the component fibres and the estimation of the volume of the fabric from measurement of length, width and thickness.

Skinkle points out that the type of finish given to a fabric can have a considerable effect on the permeability even though the porosity may remain the same.

IX.3.4 Measurement Of Air Permeability Of Plain Knit Cotton Fabrics

The method used to measure the air permeability is described in Chapter V. Using this method, seven readings were obtained, in different parts of each sample. The results are recorded in appendices 50 to 53. The average rate of air velocity from the five middle readings was calculated for each sample.

It is to be noted that the cross sectional area of the air passing through the fabric was 1 cm^2, so that the volume of air passing per second was given by:

volume of air in cm^3 per second = air velocity X 100cm./sec.

It is also to be noted, (see section V.5) that the wind tunnel apparatus used to measure the air permeability, required a 5cm. drop in pressure across the fabric, rather than the 1cm. pressure drop stipulated in the definition of air permeability.

On the assumption that the volume of air transmitted increases linearly with pressure drop, the air permeability as defined[55] was calculated from the air velocity results by the following formula:

$$\text{air permeability} = \frac{\text{air velocity (measured at 5cm. pressure drop)}}{5}$$

IX.3.5 Results And Discussion

The obtained results for air permeability are tabulated in Table(9.2). The values of air permeability (A.P.) were plotted against stitch length (ℓ) in Figure(9.3), and plotted against percentage of space, which is not occupied by yarns, i.e., (1 – C.F.) X 100% in Figure(9.4) (The

Stitch length (cm.)	Air-velocity (m/sec.)	Air-permeability (A.P.)	Air-space (1–C.F.)%	$\frac{(1-C.F.)}{\sqrt{1-(1-C.F.)^2}}$
		(D.R.)		
0.541	12.11	242.2	48	55
0.463	10.40	208.0	44	49
0.411	8.84	176.8	40	44
0.379	6.95	139.0	29	30
		(W.R.)		
0.541	8.23	164.6	41	45
0.463	6.29	125.8	33	35
0.411	4.43	88.6	25	26
0.379	3.07	61.4	14	14
		(W.M.+T.D.)		
0.541	8.21	164.2	34	36
0.463	5.43	108.6	26	27
0.411	4.09	81.8	21	21
0.379	2.75	55.0	11	11
		(M.+T.D.)		
0.428	2.69	53.8	14	14
0.381	1.91	38.2	2	2
0.355	1.44	28.8	-3	
0.330	1.05	21.0	-13	

Table(9.2) The air permeability values of plain knit cotton fabrics after different relaxation treatments.

method of calculation of the percentage of air space and their results are given in Appendix 54). As to be expected, with increase of stitch length the air permeability increased (as shown in Figure 9.3), i.e., the more open the fabric the greater the air flow through the fabric. Figure(9.4) shows that with decrease of the air space, the air permeability decreases.

In addition (see Figure 9.5) the air permeability is plotted against $(1 - C.F.)/\sqrt{1 - (1 - C.F.)^2}$. It is clear from this graph, that, as would be expected from the theoretical consideration given in IX.3.3, the results are well represented by a straight line graph passing through the origin, the equation of this general relationship is given by :

$$\text{air permeability} = \frac{4.11(1 - C.F.)}{\sqrt{1 - (1 - C.F.)^2}}$$

The fact that the results are so well represented by this general relationship, is a clear indication that:

i) the calculated value for cover factor (allowing for the density of the fibre) is a good estimation of the air space available in the fabric, since the general relationship suggests that when the fraction of space is zero, then the air permeability is zero;

ii) after washing and tumble drying, the fraction of space not covered by the yarn decreases, with a consequent large decrease in air permeability, but there is still, even with the tightest of the knitted samples, 10% air space left in the fabric.

It may be noted that for the fabrics after mercerizing, the calculated cover factor on two of these samples is greater than 1.0 (physically a meaningless figure). For these two samples, it is not possible to plot these results on Figure(9.5). However, the two other mercerized samples giving cover factor of less than one, seem to fit perfectly well onto the same general graph, suggesting that the same relationship between air permeability and cover factor applies after the mercerizing treatment.

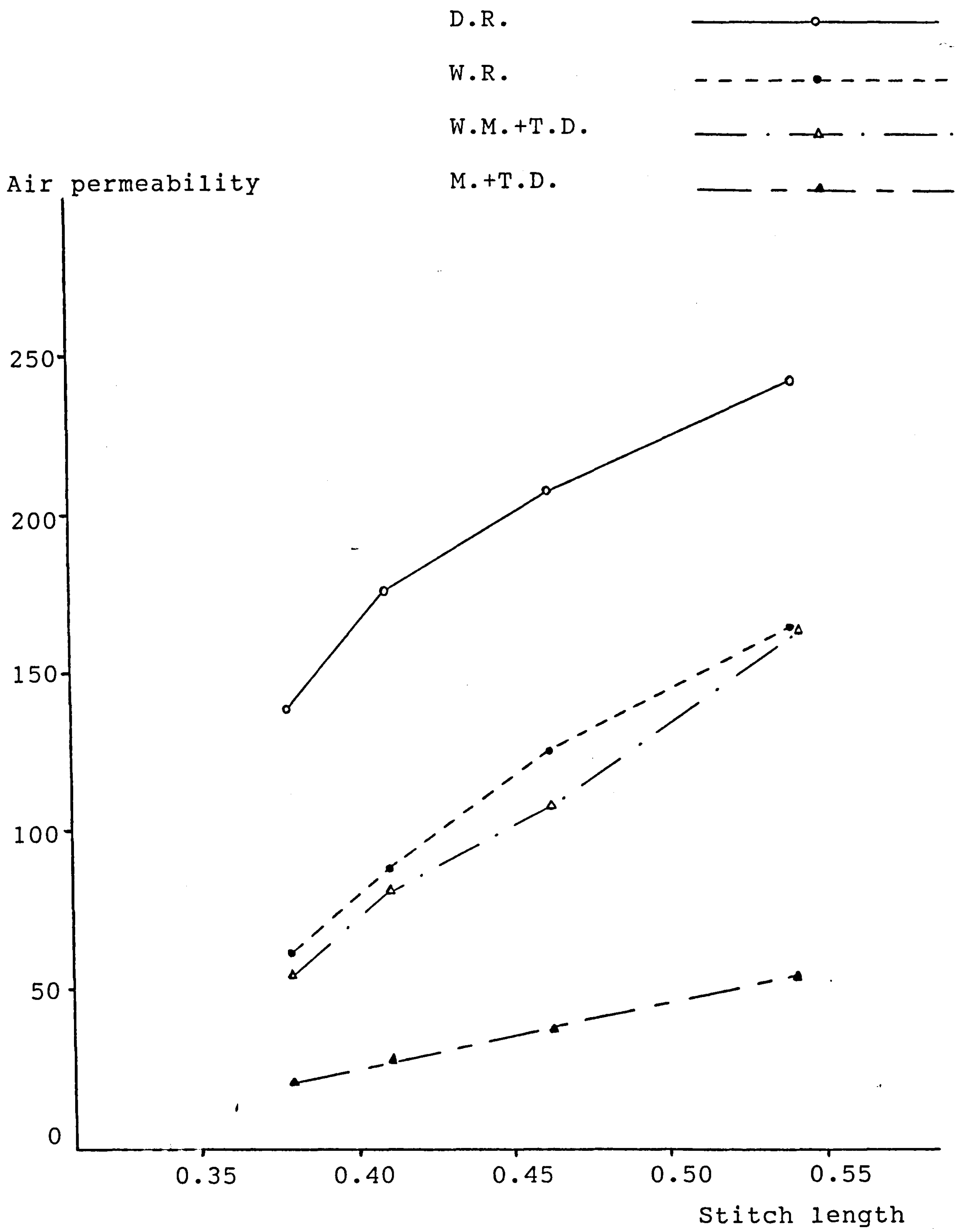
The results for the two more tightly knitted samples after mercerizing (given C.F.$>$1.0) suggests that after this treatment, either other factors such as fibre compression have been responsible for the results, or that when extremely dense knitted fabrics are produced, the small flow of air through the fabric is caused by effects other than the fraction of space available.

IX.3.6 Conclusion

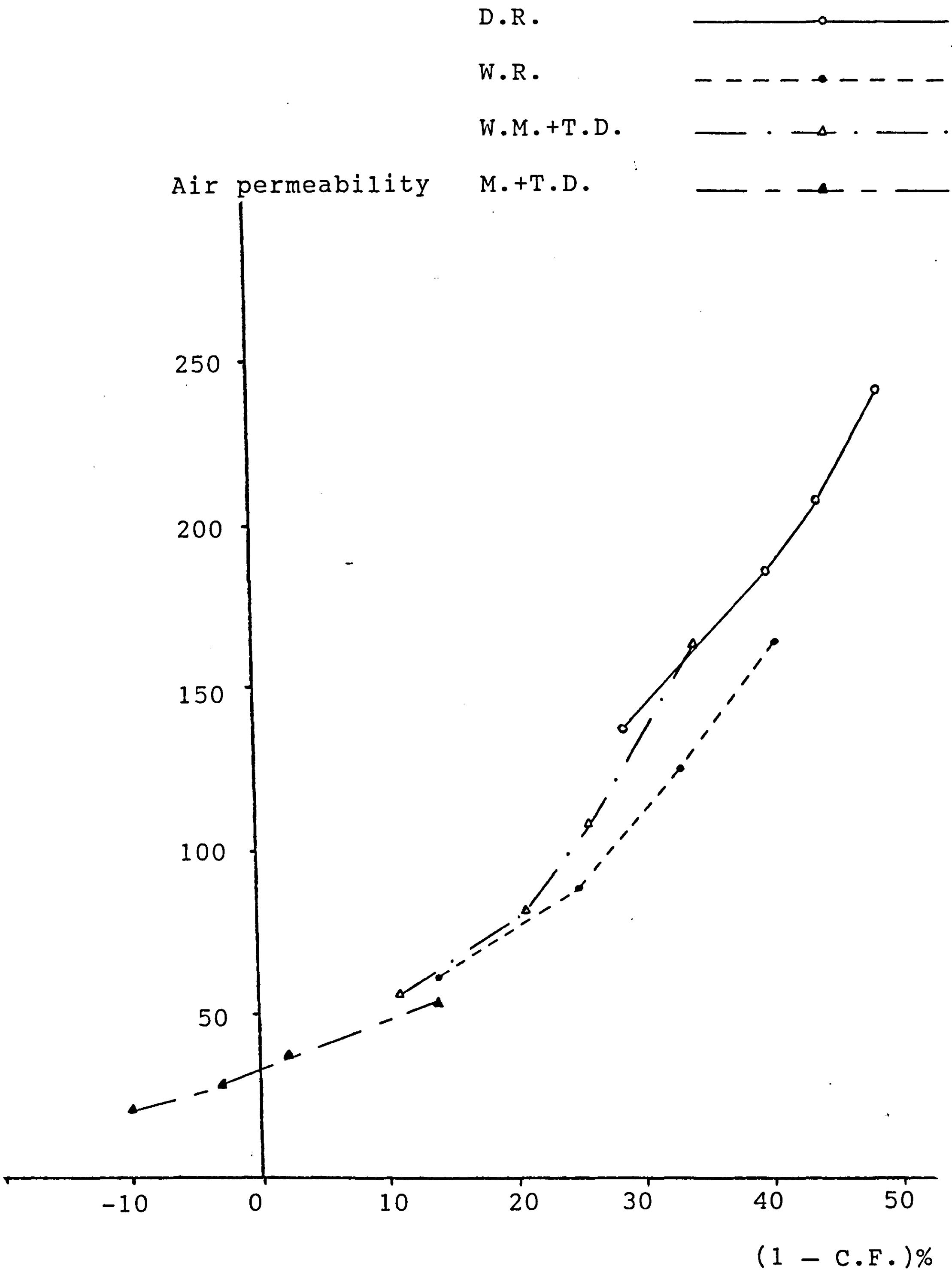
The air permeability experimental results are in agreement with the theoretical model for flow of fabric through a porous material, and confirm that the assessment of space left between the fibres calculated from the values of (1 – C.F.)% is an accurate assessment of the actual space through which air can pass through the fabric.

The results also suggest that for the plain fabric after washing and tumbling, the air space between the fibres is still large, (greater than 10% of the fabric sample area), but that after mercerizing, the air space becomes very small, and perhaps in some cases (the tightly knitted samples) the air space disappears altogether.

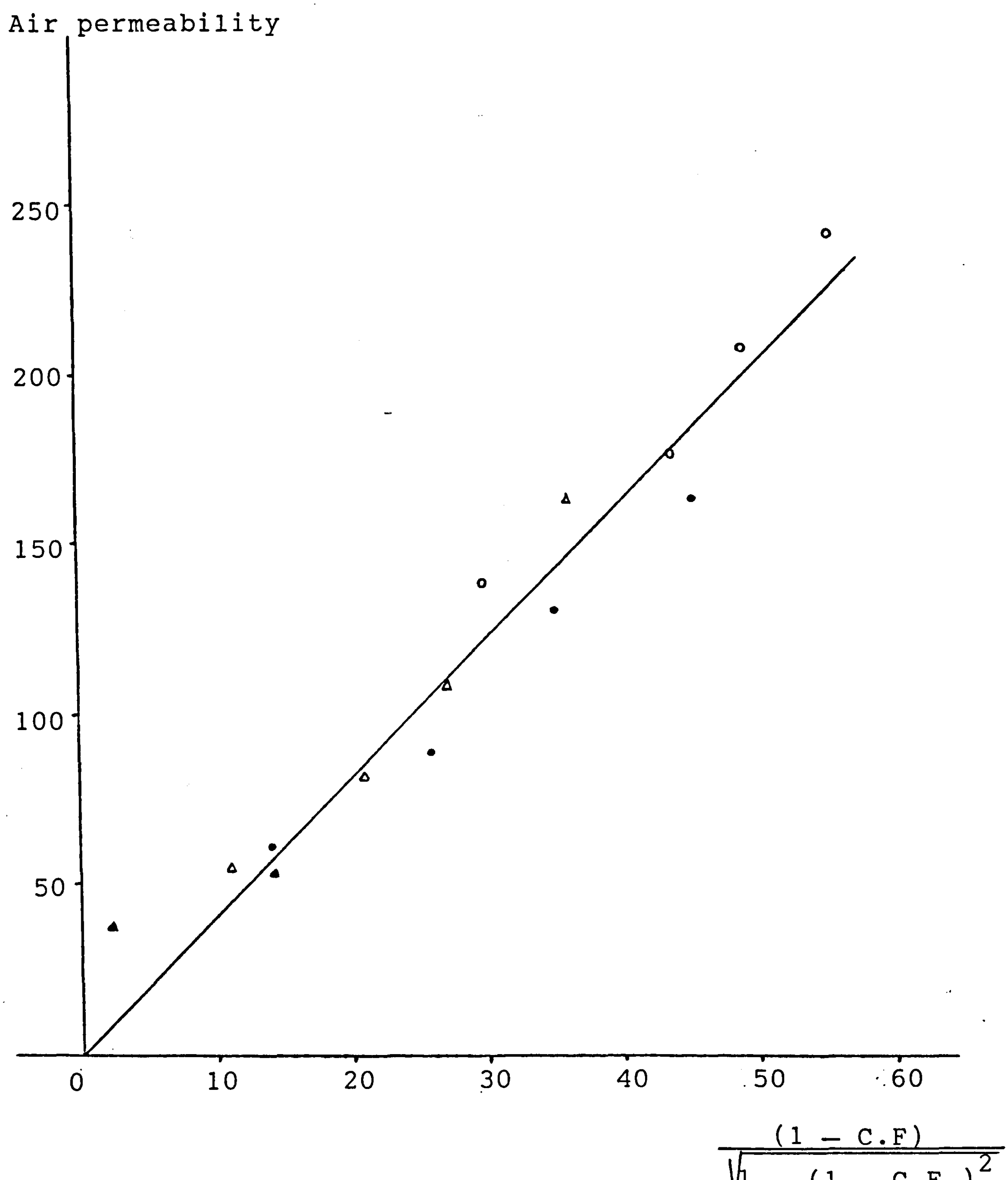
This is in accord with the concept that "full relaxation", (i.e., in the case of plain fabric after mercerizing (see section IX.2.1)), corresponds to the state of full consolidation or compression, where all air space between the fibres is eliminated.



Figure(9.3) The air permeability of plain knitted cotton fabric versus the stitch length at different relaxation treatments.



Figure(9.4) The air permeability of plain knitted cotton fabric versus the fraction of space not covered by yarn at different relaxation treatments.



Figure(9.5) The air permeability of plain knitted cotton fabric versus $\dfrac{(1 - C.F.)}{\sqrt{1 - (1 - C.F.)^2}}$ values.

CHAPTER X

CONCLUSIONS

Conclusions

From the work described in this thesis the following conclusions have been obtained:

i) Initially the effectiveness of a range of relaxation treatments on weft cotton knitted fabrics was investigated.

The measurements of "K_s" values of the individual structures (interlock, rib and plain) after each different relaxation treatment showed that with increased relaxation, this dimensional parameter of the fabrics increased, and this increase occured mainly as a result of the wet relaxation treatment.

ii) It has been previously observed for wool plain knit fabrics that the fabric dimensional parameters are constant with fabric tightness, particularly in the fully relaxed state. Examination of the effect of this stage of relaxation (i.e., washing and tumbling) on the cotton fabric parameters indicated that, in the case of rib and plain structures the "K_s" values do not vary with stitch length of the sample; for interlock structure, however, the "K_s" value varied with stitch length. These results were confirmed by statistical analysis.

iii) In this work it was found that, the "K_s" values of cotton fabrics are higher considerably, after a washing and tumbling relaxation treatment, than those found for wool fabrics by previous workers. However, there is an exception in the case of plain fabric, where the difference is not very significant.

Theoretically, the following relationships were found between the "K_s" value and the specific density of the fibre used in the fabric:

$$K_s = \frac{C . \sqrt{10^5 \pi} . \sqrt{\rho}}{2K}$$

where C, K and ρ are cover factor, tightness factor and specific density of the fibre respectively. Thus, for two fabrics having the same cover factor and if these fabrics are knitted with yarns of same Tex and same stitch length then:

$$\frac{K_{s1}}{K_{s2}} = \frac{\sqrt{\rho_1}}{\sqrt{\rho_2}}$$

Thus, the differences in "K_s" values observed for the rib and interlock fabrics, in the case of cotton and wool fibres, were explained by this analysis. However the fact that no such difference was observed with the plain fabric, suggested that, the plain cotton fabric after washing and tumble drying had not achieved its full relaxation state.

iv) It was found experimentally and statistically that, the fabrics relaxed to the same dimensions after washing and tumbling whether this is done immediately on the sample after knitting or in gradual stages of relaxation.

v) The effect of the caustic soda treatment and mercerizing on the dimensions of the fabrics after subsequent washing and tumble drying revealed that after the caustic soda treatment the increase of "K_s" value was only small, but in contrast, after mercerizing treatment, the "K_s" values increased by a very significant amount. One obvious factor responsible for these effects is the shrinkage of the yarns of the fabrics during the mercerizing treatment.

vi) By using the shrunk stitch length to calculate the fabrics "K_s" values after mercerizing treatment, it was established statistically that, in the case of interlock, the variation of "K_s" versus stitch length was non-significant, whereas, this variation in plain and rib fabrics was shown significant at the 1% level. These relationships are quite different from those obtained in the non-mercerized fabrics after a washing and tumble drying relaxation.

vii) The average "K_s" value for interlock and rib structures, after mercerizing, when calculated using the shrunk stitch length are not significantly different from those obtained after the washing and tumble drying stage. In the case of plain fabric, the "K_s" values after mercerizing, were much greater than after the washing and tumbling stage, i.e., in plain fabrics, after mercerizing, more complete relaxation occured.

viii) The "K_r" values for all structures increased considerably after wet relaxation, but in further relaxation little change was observed. A greater change was also observed in "K_r" values for slacker fabrics than tighter fabrics during the relaxation treatments.

ix) The "K_r" value which were obtained for cotton fabrics in this work are similar to those found by previous workers for wool fabrics.

x) For interlock structure, not only the "K_s" value changes with stitch length, but it was observed that the width/length ratio of the loop (K_r) decreased with increase in stitch length. However, after the mercerizing treatment, the "K_r" value increases with increase in stitch length. These effects which are quite significant have not been pointed out by previous investigators.

xi) For plain and rib structures, there was clear evidence that in the dry relaxed state, the "K_r" value changed with stitch length, but after further relaxation this effect decreased. After the mercerizing treatment, the "K_r" value was found to be independent of the stitch length.

xii) Greater "K_r" values were obtained on all the cotton fabrics after mercerization than those previously given by previous workers for wool fabrics after full relaxation. This could imply that during mercerizing, considerable distortion to the cotton loop occurs causing the loop to take up a different natural configuration.

xiii) The value of air space (1 – C.F.)% for fabrics after all stages of relaxation was calculated and it was found that with increase in severity of the relaxation treatment this figure decreased significantly.

xiv) The air permeability of the plain knit fabrics was measured for all stages of relaxation using a wind tunnel method. The experimental results obtained were accurately in agreement with those calculated from a theoretical model relating air permeability to fraction of space available for air flow.

This confirmed the analysis of the fabric structures at each stage of relaxation in terms of the calculated air space.

xv) The results also suggest that after mercerization, the plain fabric had compacted to such an extent that there was virtually no free air space left between the fibres.

This suggests that the "fully relaxed" state (in the case of plain fabrics after mercerization) is the condition where the fabric has compacted or been compressed to a state where no air space is left between the yarn forming the loops.

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APPENDICES

Sample	Feed 1 (cm.)	Feed 2 (cm.)	Feed 3 (cm.)	Feed 4 (cm.)	Average (cm.)	Stitch length (cm.)
I.1	439.0	441.1	439.8	438.2	439.5	0.436
I.2	391.0	388.7	389.1	385.2	388.5	0.385
I.3	359.1	362.0	362.1	358.1	360.3	0.357
I.4	336.8	336.6	339.8	338.9	338.0	0.335
R.1.1	401.2	401.9	405.8	403.2	403.0	0.509
R.1.2	364.3	366.9	369.2	369.6	367.5	0.464
R.1.3	333.3	331.5	328.8	327.8	330.3	0.417
R.1.4	311.4	309.8	314.4	313.9	312.4	0.394
R.2.1	398.2	402.2	401.0	399.3	400.2	0.505
R.2.2	366.2	365.3	369.7	373.1	368.8	0.466
R.2.3	327.0	322.7	326.1	331.5	326.8	0.413
R.2.4	313.6	312.0	308.5	307.2	310.3	0.392
R.3.1	400.9	402.7	405.8	407.4	404.2	0.510
R.3.2	372.0	369.7	370.3	371.9	371.0	0.468
R.3.3	331.0	333.5	334.2	330.1	332.2	0.419
R.3.4	313.8	310.9	309.8	311.1	311.4	0.393

Appendix 1 (a) The measurement of stitch length of the Interlock and Rib fabrics by unroving.

Sample	P.1	P.2	P.3	P.4
Feed 1 (cm.)	821.0	702.0	612.9	573.5
Feed 2 (cm.)	818.3	689.8	624.9	566.9
Feed 3 (cm.)	796.8	711.2	609.5	577.2
Feed 4 (cm.)	800.4	709.5	606.0	572.4
Feed 5 (cm.)	817.0	682.4	622.0	566.1
Feed 6 (cm.)	798.3	688.7	619.0	562.6
Feed 7 (cm.)	823.3	692.0	618.1	558.0
Feed 8 (cm.)	819.5	684.6	617.0	575.0
Average (cm.)	811.8	695.0	616.2	569.0
Stitch-length (cm.)	0.541	0.463	0.411	0.379
Yarn speed (m/min.)	118.9	109.7	100.6	85.3

Appendix 1 (b) The measurement of stitch length of the Plain fabrics by unroving.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
I.1	1	24.5	24.3	24.7	24.5		24.0	23.6	23.7	23.8	
	2	24.6	24.4	24.6	24.5	24.5	24.4	24.0	23.8	24.1	24.0
	3	24.6	24.4	24.5	24.5		24.2	24.0	23.9	24.0	
I.2	1	24.9	24.9	24.9	24.9		24.6	24.4	24.6	24.5	
	2	24.9	24.9	24.9	24.9	24.9	24.6	24.4	24.5	24.5	24.6
	3	24.8	24.9	24.9	24.9		25.0	24.7	24.6	24.8	
I.3	1	24.9	24.8	24.9	24.9		24.8	24.5	24.4	24.6	
	2	24.9	24.9	24.9	24.9	24.9	24.9	24.8	24.8	24.8	24.7
	3	25.0	24.9	24.9	24.9		24.6	24.6	24.9	24.7	
I.4	1	24.8	24.7	24.8	24.8		25.0	25.0	25.0	25.0	
	2	24.9	24.7	24.8	24.8	24.8	25.1	25.1	25.2	25.1	25.0
	3	24.9	24.7	24.8	24.8		25.2	25.0	24.9	25.0	

Appendix 2 The length and width of the interlock fabrics after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
P.1	1	25.0	24.9	24.9	24.9		25.1	25.0	25.0	25.0	
	2	25.0	24.9	24.9	24.9	24.9	25.0	25.0	25.0	25.0	25.0
	3	25.1	24.9	24.9	25.0		25.0	25.0	24.9	25.0	
P.2	1	25.0	24.9	25.0	25.0		25.0	25.1	25.1	25.1	
	2	25.0	25.0	25.0	25.0	25.0	25.0	25.0	24.9	25.0	25.0
	3	25.0	25.0	25.0	25.0		25.2	25.0	24.9	25.0	
P.3	1	24.9	24.9	24.9	24.9		25.1	25.0	25.0	25.0	
	2	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
	3	25.0	25.0	25.0	25.0		25.0	25.0	25.0	25.0	
P.4	1	24.9	24.9	24.9	24.9		24.8	24.9	25.0	24.9	
	2	24.9	24.9	24.9	24.9	24.9	24.9	24.9	25.0	24.9	24.9
	3	24.8	24.8	24.9	24.8		24.9	24.9	25.0	24.9	

Appendix 3 The length and width of the plain fabrics after dry relaxation.

Sample	No.	The length of fabric (cm.) 1	2	3	Average	Mean	The width of fabric (cm.) 1	2	3	Average	Mean
R.1.1	1	24.8	24.6	24.8	24.7		25.0	25.0	25,0	25.0	
	2	24.5	24.6	24.7	24.6	24.7	24.9	25.0	25.0	25.0	25.0
	3	24.8	24.7	24.7	24.7		24.8	24.9	25.0	24.9	
R.1.2	1	24.9	24.9	24.8	24.9		24.9	24.6	24.6	24.7	
	2	24.9	25.0	24.8	24.9	24.9	24.8	24.7	24.8	24.8	24.7
	3	24.9	24.9	24.9	24.9		24.8	24.7	24.7	24.7	
R.1.3	1	24.9	24.9	24.9	24.9		24.9	24.7	24.8	24.8	
	2	24.9	24.8	24.9	24.9	24.9	24.9	24.9	24.8	24.9	24.9
	3	25.0	24.9	24.9	24.9		25.0	24.9	24.8	24.9	
R,1.4	1	24.8	24.8	24.9	24.8		24.8	24.6	24.7	24.7	
	2	24.8	24.7	24.9	24.8	24.8	24.8	24.8	24.9	24.8	24.8
	3	24.8	24.8	24.9	24.8		24.8	24.8	24.7	24.8	

Appendix 4 The legth and width of the rib fabrics (with single yarn) after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.2.1	1	24.8	24.7	24.8	24.8		25.0	25.0	24.8	24.9	
	2	24.8	24.7	24.8	24.8	24.8	25.0	24.9	25.0	25.0	25.0
	3	24.8	24.8	24.9	24.8		25.0	25.0	25.0	25.0	
R.2.2	1	24.9	24.9	24.9	24.9		24.9	24.9	24.9	24.9	
	2	24.9	24.8	24.9	24.9	24.9	25.0	25.0	24.8	24.9	24.9
	3	25.0	24.9	24.9	24.9		25.0	25.0	24.9	25.0	
R.2.3	1	24.9	24.8	24.9	24.9		24.9	24.9	25.0	24.9	
	2	25.0	24.8	24.9	24.9	24.9	25.0	24.9	24.9	24.9	24.9
	3	24.9	24.8	25.0	24.9		25.0	25.0	24.9	25.0	
R.2.4	1	24.9	24.8	24.8	24.8		24.8	24.8	24.8	24.8	
	2	24.7	24.7	24.8	24.8	24.8	24.9	24.9	24.8	24.9	24.9
	3	24.8	24.7	24.8	24.8		25.0	24.9	24.8	24.9	

Appendix 5 The length and width of the rib fabrics (with two-fold yarn) after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.3.1	1	24.7	24.6	24.8	24.7		24.7	24.8	25.0	24.8	
	2	24.8	24.7	24.7	24.7	24.7	24.7	24.8	24.9	24.8	24.8
	3	24.8	24.7	24.8	24.8		24.7	24.7	24.9	24.8	
R.3.2	1	24.9	24.7	24.9	24.8		24.5	24.5	24.5	24.5	
	2	24.9	24.9	24.8	24.9	24.8	24.7	24.6	24.4	24.6	24.6
	3	24.9	24.8	24.8	24.8		24.7	24.7	24.5	24.6	
R.3.3	1	25.0	24.9	24.9	24.9		24.7	24.6	24.7	24.7	
	2	24.9	24.7	24.9	24.8	24.8	24.8	24.7	24.7	24.7	24.7
	3	24.9	24.7	24.8	24.8		24.8	24.7	24.7	24.7	
R.3.4	1	24.9	24.9	24.8	24.9		24.7	24.4	24.8	24.6	
	2	24.9	24.8	24.8	24.8	24.9	24.6	24.5	24.5	24.5	24.5
	3	25.0	24.9	24.8	24.9		24.6	24.5	24.5	24.5	

Appendix 6 The length and width of the rib fabrics (with two-ends yarn) after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
I.1	1	19.0	18.6	18.9	18.8		27.0	26.5	27.9	27.1	
	2	19.1	18.2	18.9	18.7	18.6	26.6	25.5	26.4	26.2	27.1
	3	18.8	18.0	18.4	18.4		28.3	28.0	27.6	28.0	
I.2	1	19.3	18.8	19.1	19.1		25.8	25.3	25.4	25.5	
	2	18.9	19.1	19.4	19.1	19.1	26.3	25.4	25.2	25.6	25.7
	3	19.4	18.5	19.4	19.1		26.3	25.9	26.0	26.1	
I.3	1	19.9	19.2	19.9	19.7		25.6	24.9	24.7	25.1	
	2	20.0	19.7	20.0	19.9	19.9	25.1	24.4	24.2	24.6	24.8
	3	20.6	19.8	20.3	20.2		24.7	24.3	24.9	24.6	
I.4	1	19.9	19.6	20.3	19.9		24.3	24.4	24.6	24.4	
	2	20.3	19.8	20.1	20.1	19.9	24.5	24.2	24.2	24.3	24.4
	3	19.8	19.6	20.0	19.8		24.4	24.1	24.6	24.4	

Appendix 7 The length and width of the interlock fabrics after wet relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
P.1	1	19.8	19.2	20.1	19.7		27.8	28.3	28.0	28.0	
	2	20.7	20.3	20.3	20.4	20.1	26.2	26.4	27.0	26.5	27.4
	3	20.2	19.5	20.7	20.1		28.5	27.5	27.4	27.8	
P.2	1	20.9	21.1	21.2	21.1		25.5	24.8	25.1	25.1	
	2	21.2	21.0	21.4	21.2	21.0	25.3	24.8	25.1	25.1	25.0
	3	21.1	20.4	20.8	20.8		24.8	24.6	25.0	24.8	
P.3	1	21.3	21.3	21.4	21.3		23.6	23.2	23.5	23.4	
	2	21.6	21.0	21.2	21.3	21.4	23.8	23.6	23.7	23.7	23.5
	3	21.6	21.3	21.5	21.5		23.3	23.2	23.3	23.3	
P.4	1	23.8	23.8	23.7	23.8		21.5	21.6	21.8	21.6	
	2	23.7	23.7	24.0	23.8	23.8	21.7	21.4	21.8	21.6	21.5
	3	24.0	23.7	23.6	23.8		21.4	21.1	21.5	21.3	

Appendix 8 The length and width of the plain fabrics after wet relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.1.1	1	19.8	18.3	19.5	19.2		28.5	28.2	28.8	28.5	
	2	19.3	19.0	20.2	19.5	19.3	27.3	26.2	26.7	26.7	27.8
	3	19.1	18.8	20.1	19.3		28.2	28.0	28.1	28.1	
R.1.2	1	20.7	19.9	20.2	20.3		25.5	24.5	25.3	25.1	
	2	20.7	19.8	20.1	20.2	20.2	25.3	24.9	25.1	25.1	25.3
	3	20.3	19.5	20.4	20.1		25.7	25.2	26.2	25.7	
R.1.3	1	21.4	20.6	21.6	21.2		23.4	23.2	23.3	23.3	
	2	21.4	20.7	21.6	21.2	21.1	23.6	23.0	23.9	23.5	23.3
	3	21.4	20.5	21.0	21.0		23.4	22.8	23.1	23.1	
R.1.4	1	21.9	21.1	21.8	21.9		22.6	22.2	22.2	22.3	
	2	21.7	21.0	22.0	21.6	21.7	22.7	22.2	22.4	22.4	22.3
	3	21.8	21.1	21.8	21.6		22.4	21.9	22.4	22.2	

Appendix 9 The length and width of the rib fabrics (with single yarn) after wet relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.2.1	1	20.5	19.6	20.2	20.1		24.9	24.8	24.4	24.7	
	2	20.3	19.5	20.2	20.0	20.0	25.6	25.4	25.4	25.5	25.1
	3	20.1	19.5	20.4	20.0		25.3	24.9	25.3	25.2	
R.2.2	1	21.4	20.3	20.7	20.8		24.1	23.8	23.9	23.9	
	2	21.2	19.9	21.2	21.1	20.9	24.6	23.5	23.6	23.9	23.9
	3	20.8	20.4	21.0	20.7		24.2	23.7	24.1	24.0	
R.2.3	1	21.2	20.4	21.4	21.0		23.4	23.4	23.1	23.3	
	2	21.3	20.9	21.5	21.2	21.1	23.6	23.2	23.3	23.4	23.2
	3	21.2	20.8	21.4	21.1		23.2	22.8	22.8	22.9	
R.2.4	1	21.9	21.3	21.8	21.7		22.2	22.2	22.5	22.3	
	2	21.9	21.2	22.0	21.7	21.8	22.4	22.3	22.5	22.4	22.3
	3	22.0	21.6	22.0	21.9		22.2	22.2	22.6	22.3	

Appendix 10 The length and width of the rib fabrics (with two-fold yarn) after wet relaxation.

Sample	No.	The length of fabric (cm.) 1	2	3	Average	Mean	The width of fabric (cm.) 1	2	3	Average	Mean
R.3.1	1	20.1	18.8	20.5	19.8		27.7	28.1	28.5	28.1	
	2	20.3	19.6	20.4	20.1	20.1	27.6	27.6	28.0	27.7	27.5
	3	20.7	19.5	20.7	20.3		26.4	26.7	27.0	26.7	
R.3.2	1	21.2	20.1	21.2	20.8		25.1	24.8	25.1	25.0	
	2	20.7	20.0	21.1	20.6	20.8	24.7	24.9	24.7	24.8	24.9
	3	21.7	19.8	21.1	20.9		24.9	25.3	24.8	25.0	
R.3.3	1	21.3	20.2	20.9	20.8		23.2	23.2	23.5	23.3	
	2	21.4	20.2	21.2	20.9	20.8	23.1	22.8	22.6	22.8	23.1
	3	21.3	20.1	21.0	20.8		23.4	23.3	22.8	23.2	
R.3.4	1	22.6	21.7	21.8	22.0		21.8	21.8	21.6	21.7	
	2	22.0	21.3	22.2	21.8	21.9	21.8	22.0	22.0	21.9	21.8
	3	22.3	21.5	21.8	21.9		21.8	21.6	21.7	21.7	

Appendix 11 The length and width of the rib fabrics (with two-ends yarn) after wet relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
	1	17.8	17.5	17.8	17.7		23.5	23.2	23.2	23.3	
I.1	2	17.8	17.3	17.8	17.6	17.6	23.6	22.9	23.0	23.2	23.3
	3	17.6	17.2	17.5	17.4		23.7	23.5	23.4	23.5	
	1	17.9	18.0	18.0	18.0		22.4	22.2	22.5	22.4	
I.2	2	17.8	17.9	18.0	17.9	17.9	22.6	22.2	22.4	22.4	22.6
	3	17.8	17.6	17.8	17.7		23.2	22.9	22.7	22.9	
	1	18.5	18.6	18.6	18.6		22.7	22.3	22.1	22.4	
I.3	2	18.7	18.6	18.9	18.7	18.7	22.6	22.6	22.6	22.6	22.5
	3	19.0	18.7	18.7	18.8		22.4	22.3	22.4	22.4	
	1	18.7	18.7	18.8	18.7		22.8	22.7	22.9	22.8	
I.4	2	18.8	18.8	18.8	18.8	18.7	22.9	22.7	22.7	22.8	22.8
	3	18.7	18.7	18.8	18.7		22.8	22.5	22.7	22.7	

Appendix 12 The length and width of the interlock fabrics after wet relaxation and tumble drying.

Sample	No.	The length of fabric (cm.) 1	2	3	Average	Mean	The width of fabric (cm.) 1	2	3	Average	Mean
P.1	1	18.8	18.5	18.6	18.6		26.2	26.1	25.8	26.0	
	2	19.1	18.9	18.9	19.0	18.8	25.3	25.5	25.7	25.5	25.8
	3	19.2	18.5	19.1	18.9		26.3	26.0	25.8	26.0	
P.2	1	20.0	20.2	20.1	20.1		24.0	24.1	23.9	24.0	
	2	20.2	20.1	20.1	20.1	20.0	23.9	23.8	23.8	23.8	23.9
	3	19.9	19.7	19.6	19.7		24.0	23.7	23.8	23.8	
P.3	1	20.4	20.5	20.5	20.5		22.5	22.1	22.3	22.3	
	2	20.5	20.3	20.4	20.4	20.5	22.8	22.7	22.8	22.8	22.5
	3	20.5	20.5	20.5	20.5		22.6	22.4	22.4	22.5	
P.4	1	23.2	23.2	23.1	23.2		20.8	20.8	21.1	20.9	
	2	23.1	23.2	23.3	23.2	23.2	21.0	20.8	21.1	21.0	20.8
	3	23.2	23.1	23.1	23.1		20.5	20.3	20.6	20.4	

Appendix 13 The length and width of the plain fabrics after wet relaxation and tumble drying.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.1.1	1	18.1	17.5	18.2	17.9		25.4	25.9	25.9	25.7	
	2	17.8	17.6	18.2	17.9	17.9	25.5	25.2	25.3	25.3	25.5
	3	17.9	17.5	18.4	17.9		25.5	25.6	25.6	25.6	
R.1.2	1	19.2	18.7	19.2	19.0		23.6	23.0	23.2	23.3	
	2	19.4	18.8	19.0	19.1	19.0	22.9	23.1	23.2	23.1	23.2
	3	19.0	18.5	19.2	18.9		23.3	23.2	23.5	23.3	
R.1.3	1	20.3	19.8	20.2	20.1		21.6	21.5	21.6	21.6	
	2	20.1	19.7	20.2	20.0	20.0	21.8	21.8	21.7	21.8	21.6
	3	20.1	19.6	20.2	20.0		21.4	21.5	21.6	21.5	
R.1.4	1	20.9	20.5	20.9	20.8		20.7	20.4	20.4	20.5	
	2	20.8	20.3	21.0	20.7	20.7	20.9	20.8	20.8	20.8	20.6
	3	20.9	20.4	20.9	20.7		20.4	20.5	20.6	20.5	

Appendix 14 The length and width of the rib fabrics (with single yarn) after wet relaxation and tumble drying.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.2.1	1	19.0	18.7	19.2	19.0		23.5	23.5	23.3	23.4	
	2	19.0	18.4	19.1	18.8	18.9	23.6	23.6	23.7	23.6	23.5
	3	19.1	18.6	19.0	18.9		23.7	23.4	23.7	23.6	
R.2.2	1	20.1	19.4	19.8	19.7		22.2	22.0	22.4	22.2	
	2	20.0	19.1	20.0	19.7	19.7	22.6	22.2	22.2	22.3	22.2
	3	19.8	19.5	20.1	19.7		22.2	22.0	22.2	22.1	
R.2.3	1	20.5	20.2	20.5	20.4		21.5	21.9	21.7	21.7	
	2	20.7	20.3	20.8	20.6	20.5	21.9	22.0	21.6	21.8	21.7
	3	20.7	20.3	20.8	20.6		21.7	21.7	21.4	21.6	
R.2.4	1	21.3	21.0	21.3	21.2		20.9	21.0	21.0	21.0	
	2	21.2	20.8	21.3	21.1	21.2	21.1	21.1	21.0	21.1	21.0
	3	21.2	21.0	21.4	21.2		21.0	21.0	21.1	21.0	

Appendix 15 The length and width of the rib fabrics (with two-fold yarn) after wet relaxation and tumble drying.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.3.1	1	18.4	17.8	18.6	18.3		26.2	26.4	26.0	26.2	
	2	18.3	18.0	18.6	18.3	18.3	25.7	26.1	26.0	25.9	26.0
	3	18.5	17.8	18.8	18.4		25.6	26.1	25.9	25.9	
R.3.2	1	19.9	19.2	19.9	19.7		23.4	23.7	23.5	23.5	
	2	19.7	19.1	19.8	19.5	19.6	23.5	23.6	23.7	23.6	23.6
	3	20.1	19.0	19.9	19.7		23.7	24.2	23.4	23.8	
R.3.3	1	20.4	19.6	20.1	20.0		21.6	21.8	21.9	21.8	
	2	20.2	19.5	20.3	20.0	20.0	21.6	21.7	21.5	21.6	21.7
	3	20.3	19.5	20.2	20.0		21.7	22.0	21.8	21.8	
R.3.4	1	21.9	21.2	21.4	21.5		20.3	20.4	20.2	20.3	
	2	21.5	21.1	21.7	21.4	21.5	20.4	20.4	20.2	20.3	20.3
	3	21.8	21.1	21.5	21.5		20.5	20.4	20.3	20.4	

Appendix 16 The length and width of the rib fabrics (with two-ends yarn) after wet relaxation and tumble drying.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
I.1	1	17.4	17.2	17.6	17.4		25.1	25.1	25.1	25.1	
	2	17.5	16.6	17.4	17.2	17.2	25.5	25.2	24.7	25.1	25.6
	3	17.5	16.4	17.2	17.0		26.4	26.8	26.4	26.5	
I.2	1	17.5	17.6	17.8	17.6		23.6	23.4	23.6	23.5	
	2	17.5	17.3	17.8	17.5	17.5	23.5	23.7	23.7	23.6	23.7
	3	17.7	17.1	17.5	17.4		24.2	24.4	23.8	24.1	
I.3	1	18.0	17.9	18.2	18.0		24.1	23.5	22.9	23.5	
	2	18.5	18.2	18.5	18.4	18.2	23.1	23.0	22.9	23.0	23.3
	3	18.6	18.1	18.3	18.3		23.3	23.4	23.5	23.4	
I.4	1	18.3	18.1	18.5	18.3		23.2	23.3	23.3	23.3	
	2	18.2	18.1	18.5	18.3	18.3	23.5	23.4	23.6	23.5	23.3
	3	18.4	18.0	18.6	18.3		23.4	23.1	23.2	23.2	

Appendix 17 The length and width of the interlock fabrics after washing and tumble drying which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
P.1	1	18.5	18.3	18.6	18.5		26.7	26.5	26.0	26.4	
	2	18.7	18.4	18.6	18.6	18.6	25.9	26.0	26.1	26.0	26.2
	3	18.9	18.1	18.7	18.6		26.3	26.4	26.3	26.3	
P.2	1	19.9	20.0	20.0	20.0		24.2	24.1	24.0	24.1	
	2	20.0	19.9	20.1	20.0	19.9	24.3	24.3	24.1	24.2	24.1
	3	19.7	19.5	19.6	19.6		24.1	23.7	24.0	23.9	
P.3	1	20.3	20.3	20.4	20.3		22.7	22.5	22.8	22.7	
	2	20.5	20.4	20.4	20.4	20.4	23.0	22.8	22.9	22.9	22.8
	3	20.6	20.6	20.5	20.6		22.7	22.7	22.7	22.7	
P.4	1	23.2	23.4	23.3	23.3		20.9	20.9	21.2	21.0	
	2	23.2	23.2	23.4	23.3	23.3	21.1	20.8	21.0	21.0	20.8
	3	23.3	23.2	23.2	23.2		20.6	20.3	20.6	20.5	

Appendix 18 The length and width of the plain fabrics after washing and tumble drying which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.1.1	1	18.4	17.2	18.0	17.9		26.6	27.3	26.8	26.9	
	2	17.9	17.3	18.0	17.7	17.8	26.4	26.7	26.9	26.7	26.7
	3	17.8	17.0	18.3	17.7		26.3	26.6	26.7	26.5	
R.1.2	1	19.0	18.4	19.3	18.9		24.0	23.6	23.4	23.7	
	2	19.1	18.6	19.0	18.9	18.8	23.8	23.6	23.8	23.7	23.7
	3	18.6	18.1	19.1	18.6		23.7	23.8	24.0	23.8	
R.1.3	1	20.0	19.4	19.8	19.7		21.7	21.5	21.7	21.6	
	2	19.8	19.4	19.8	19.7	19.7	21.9	21.9	21.7	21.8	21.6
	3	19.8	19.3	19.9	19.7		21.3	21.4	21.4	21.4	
R.1.4	1	20.5	20.2	20.7	20.5		20.6	20.4	20.4	20.5	
	2	20.4	20.2	20.7	20.4	20.4	20.7	20.7	20.7	20.7	20.5
	3	20.5	20.1	20.6	20.4		20.2	20.4	20.5	20.4	

Appendix 19 The length and width of the rib fabrics (with single yarn) after washing and tumble drying which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.2.1	1	18.5	18.0	18.7	18.4		23.5	23.6	23.3	23.5	
	2	18.5	18.0	18.7	18.4	18.4	23.6	23.2	23.8	23.5	23.6
	3	18.6	18.1	18.6	18.4		23.5	23.5	24.0	23.7	
R.2.2	1	19.7	19.0	19.3	19.3		21.8	21.9	22.0	21.9	
	2	19.6	18.8	19.4	19.3	19.3	22.2	21.6	21.9	21.9	21.9
	3	19.4	19.0	19.8	19.4		22.0	21.8	21.8	21.9	
R.2.3	1	20.1	19.8	20.1	20.0		21.1	21.3	21.2	21.2	
	2	20.4	19.8	20.2	20.1	20.1	21.4	21.3	21.2	21.3	21.2
	3	20.2	19.7	20.3	20.1		21.2	21.2	21.0	21.1	
R.2.4	1	20.9	20.6	20.9	20.8		20.3	20.3	20.4	20.3	
	2	20.8	20.4	21.0	20.7	20.8	20.5	20.5	20.4	20.5	20.4
	3	20.9	20.6	21.1	20.9		20.4	20.5	20.4	20.4	

Appendix 20 The length and width of the rib fabrics (with two-fold yarn) after washing and tumble drying which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.3.1	1	18.1	17.2	18.2	17.8		26.5	26.9	26.7	26.7	
	2	17.8	17.4	18.1	17.8	17.8	26.4	26.9	26.6	26.6	26.6
	3	17.9	17.2	18.2	17.8		26.2	26.7	26.4	26.4	
R.3.2	1	19.4	18.7	19.4	19.2		23.3	23.5	23.6	23.5	
	2	19.1	18.6	19.2	19.0	19.1	23.4	23.6	23.5	23.5	23.6
	3	19.6	18.6	19.2	19.1		23.7	24.0	23.8	23.8	
R.3.3	1	19.9	19.2	19.6	19.6		21.3	21.4	21.5	21.4	
	2	19.6	19.0	19.8	19.5	19.5	21.5	21.4	21.2	21.4	21.4
	3	19.7	19.1	19.6	19.5		21.5	21.5	21.4	21.5	
R.3.4	1	21.4	20.7	20.9	21.0		19.7	19.7	19.6	19.7	
	2	21.0	20.6	21.2	20.9	21.0	19.6	19.8	19.6	19.7	19.7
	3	21.2	20.8	21.0	21.0		19.9	19.7	19.7	19.8	

Appendix 21 The length and width of the rib fabrics (with two-ends yarn) after washing and tumble drying which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
I.1	4	17.6	17.1	17.4	17.4		22.6	22.9	22.5	22.7	
	5	17.3	17.0	17.3	17.2	17.4	22.5	22.6	22.6	22.6	22.6
	6	17.5	17.3	17.6	17.5		22.4	22.5	22.7	22.5	
I.2	4	17.7	17.5	17.6	17.6		21.7	21.5	21.5	21.6	
	5	17.8	17.6	17.7	17.7	17.7	21.7	21.5	21.5	21.6	21.7
	6	17.8	17.8	17.9	17.8		21.8	21.8	21.8	21.8	
I.3	4	18.6	18.5	18.4	18.5		21.7	21.5	21.4	21.5	
	5	18.3	18.3	18.3	18.3	18.3	21.1	21.3	21.4	21.3	21.4
	6	18.2	18.2	17.9	18.1		21.5	21.6	21.5	21.5	
I.4	4	18.6	18.5	18.4	18.5		21.9	22.0	21.9	21.9	
	5	18.5	18.1	18.4	18.3	18.4	22.2	22.2	22.3	22.2	22.2
	6	18.4	18.3	18.5	18.4		22.9	22.5	21.8	22.4	

Appendix 22 The length and width of the interlock fabrics after washing and tumble drying immediately after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
P.1	4	19.1	19.2	19.1	19.1		25.2	25.5	25.7	25.5	
	5	18.8	18.5	18.8	18.7	18.9	25.5	25.5	25.7	25.6	25.4
	6	18.7	18.8	18.8	18.8		25.3	25.2	25.1	25.2	
P.2	4	19.3	19.1	19.4	19.3		24.4	24.4	24.4	24.4	
	5	19.6	19.4	19.5	19.5	19.4	24.1	24.2	24.0	24.1	24.3
	6	19.5	19.4	19.6	19.5		24.3	24.3	24.4	24.3	
P.3	4	20.6	20.5	20.3	20.5		22.6	22.5	22.5	22.5	
	5	20.8	20.9	20.9	20.9	20.7	22.9	22.6	22.6	22.7	22.6
	6	20.5	20.7	20.7	20.6		22.5	22.5	22.9	22.6	
P.4	4	23.4	23.3	23.2	23.3		20.7	20.8	20.9	20.8	
	5	23.6	23.7	23.6	23.6	23.4	20.4	20.5	20.9	20.6	20.6
	6	23.5	23.4	23.3	23.4		20.4	20.4	20.8	20.5	

Appendix 23 The length and width of the plain fabrics after washing and tumble drying immediately after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.1.1	4	18.2	17.6	18.5	18.1		25.7	26.0	25.6	25.8	
	5	18.0	17.5	18.3	17.9	18.0	25.5	25.7	25.7	25.6	25.6
	6	18.3	17.5	18.4	18.1		25.3	25.3	25.8	25.5	
R.1.2	4	19.2	18.4	19.1	18.9		22.8	23.1	23.1	23.0	
	5	19.3	18.5	19.3	19.0	18.9	23.0	22.9	22.8	22.9	23.0
	6	19.1	18.4	19.2	18.9		23.1	23.1	22.8	23.0	
R.1.3	4	20.1	19.8	20.1	20.0		21.4	21.3	21.1	21.3	
	5	20.1	19.7	20.3	20.0	20.0	21.5	21.4	21.5	21.5	21.3
	6	20.1	19.7	20.3	20.0		21.2	21.0	21.2	21.1	
R.1.4	4	21.0	20.7	21.1	20.9		20.0	20.2	20.3	20.2	
	5	20.8	20.5	21.0	20.8	20.9	20.1	20.2	20.1	20.1	20.1
	6	20.8	20.6	21.1	20.9		20.1	20.2	20.1	20.1	

Appendix 24 The length and width of the rib fabrics (with single yarn) after washing and tumble drying immediately after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.2.1	4	19.0	18.4	19.0	18.8		23.8	23.7	23.8	23.8	
	5	19.2	18.4	19.2	18.9	18.9	24.0	24.0	23.7	23.9	23.9
	6	19.0	18.7	19.1	18.9		24.0	24.0	23.7	23.9	23.9
R.2.2	4	20.0	19.7	20.3	20.0		22.2	21.8	21.8	21.9	
	5	20.2	19.7	20.2	20.0	20.0	22.0	22.0	22.0	22.0	21.8
	6	20.0	19.5	20.1	19.9		21.8	21.5	21.6	21.6	
R.2.3	4	20.9	20.8	21.0	20.9		21.7	21.7	21.7	21.7	
	5	21.3	20.8	21.0	21.0	20.9	22.1	22.1	21.6	21.9	21.8
	6	21.1	20.8	21.1	20.9		21.7	21.9	21.6	21.7	
R.2.4	4	21.3	21.2	21.4	21.3		21.1	21.0	20.9	21.0	
	5	21.5	21.1	21.4	21.3	21.3	20.7	20.9	20.9	20.8	20.8
	6	21.5	21.2	21.3	21.3		21.2	20.6	20.4	20.7	

Appendix 25 The length and width of the rib fabrics (with two-fold yarn) after washing and tumble drying immediately after dry relaxation.

Sample	No.	The length of fabric (cm.) 1	2	3	Average	Mean	The width of fabric (cm.) 1	2	3	Average	Mean
R.3.1	4	18.7	17.8	18.6	18.4		25.9	26.2	26.2	26.1	
	5	18.6	17.9	19.0	18.5	18.4	25.6	26.1	25.9	25.9	26.1
	6	18.5	17.8	18.7	18.3		26.1	26.4	26.0	26.2	
R.3.2	4	20.4	19.2	19.7	19.8		23.8	23.5	23.1	23.5	
	5	20.1	19.2	20.0	19.8	19.8	23.3	23.4	23.1	23.3	23.4
	6	20.1	19.3	20.1	19.8		23.6	23.6	23.3	23.5	
R.3.3	4	20.0	19.7	20.3	20.0		21.5	21.2	21.1	21.3	
	5	20.4	19.7	20.4	20.2	20.1	21.2	21.2	21.1	21.2	21.3
	6	20.2	19.7	20.4	20.1		21.3	21.5	21.4	21.4	
R.3.4	4	21.7	21.0	21.4	21.4		19.7	19.7	19.8	19.7	
	5	21.9	21.4	21.5	21.6	21.5	19.4	19.7	19.6	19.6	19.7
	6	21.7	21.0	21.4	21.4		19.7	19.8	19.6	19.7	

Appendix 26 The length and width of the rib fabrics (with two-ends yarn) after washing and tumble drying immediately after dry relaxation.

Sample		Number of measurements						Mean of	Mean of
		1	2	3	4	5	6	C.P.25cm.	W.P.25cm.
I.1	Courses	211	211	211	211	210	212	211.0	
	Wales	334	337	335	340	335	338		336.5
I.2	Courses	242	243	240	242	242	243	242.0	
	Wales	334	334	337	337	333	333		335.5
I.3	Courses	272	272	273	273	272	268	272.0	
	Wales	328	333	330	332	330	335		331.0
I.4	Courses	297	295	294	294	294	293	294.5	
	Wales	337	339	341	340	342	346		341.0
P.1	Courses	190	188	192	193	189	190	190.0	
	Wales	213	214	224	217	219	210		216.0
P.2	Courses	246	245	239	236	237	238	240.0	
	Wales	219	217	215	226	220	233		222.0
P.3	Courses	280	280	280	283	279	282	280.5	
	Wales	224	227	224	231	227	237		228.0
P.4	Courses	367	372	370	371	378	371	371.5	
	Wales	233	233	223	229	230	224		228.5
R.1.1	Courses	191	188	191	194	190	191	191.0	
	Wales	179	181	180	181	180	180		180.0
R.1.2	Courses	221	224	219	220	220	223	221.0	
	Wales	176	175	172	176	175	173		174.5
R.1.3	Courses	262	258	260	261	260	260	260.0	
	Wales	177	178	175	177	175	176		176.0
R.1.4	Courses	289	285	290	291	292	288	289.0	
	Wales	173	176	172	171	173	171		172.5

Appendix 27 The total number of courses and wales per 25 centimetres for the samples.

Sample		Number of measurements						Mean of	Mean of
		1	2	3	4	5	6	C.P.25cm.	W.P.25cm.
R.2.1	Courses	191	194	192	192	195	195	193.0	
	Wales	158	157	159	158	157	157		157.5
R.2.2	Courses	225	222	223	224	225	226	224.0	
	Wales	153	155	155	155	155	156		155.0
R.2.3	Courses	262	265	265	262	265	263	263.5	
	Wales	166	168	167	169	169	167		167.5
R.2.4	Courses	293	291	293	292	294	295	293.0	
	Wales	167	169	169	170	169	167		168.5
R.3.1	Courses	194	194	192	194	193	194	193.5	
	Wales	187	187	186	185	188	188		187.0
R.3.2	Courses	230	231	231	233	230	235	232.0	
	Wales	180	181	181	179	183	182		181.0
R.3.3	Courses	266	264	267	264	267	267	266.0	
	Wales	176	176	178	180	178	177		177.5
R.3.4	Courses	313	310	306	310	305	311	309.0	
	Wales	168	167	167	168	167	168		167.5

Appendix 27 The total number of courses and wales per 25 centimetres for the samples.

Interlock

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	1.85	0.475	0.982	$K_s = 0.475\ell + 1.85$
(W.R.)	10.76	0.359	0.992	$K_s = 0.359\ell + 10.76$
(W.R.+T.D.)	4.37	0.652	0.998	$K_s = 0.652\ell + 4.37$
G(W.M.+T.D.)	12.26	0.422	0.988	$K_s = 0.422\ell + 12.26$
(W.M.+T.D.)	5.78	0.655	0.994	$K_s = 0.655\ell + 5.78$
(W.M.+T.D.) (shrunk ℓ)	7.37	0.596	0.993	$K_s = 0.596\ell + 7.37$
G(C.S.+T.D.)	12.08	0.466	0.996	$K_s = 0.466\ell + 12.08$
G(M.+T.D.)	34.72	0.143	0.427	$K_s = 0.143\ell + 34.72$
(C.S.+T.D.)	9.91	0.503	0.986	$K_s = 0.503\ell + 9.91$
(M.+T.D.)	28.95	0.267	0.699	$K_s = 0.267\ell + 28.95$
(C.S.+T.D.) (shrunk ℓ)	9.99	0.483	0.984	$K_s = 0.483\ell + 9.99$
(M.+T.D.) (shrunk ℓ)	25.78	0.062	0.323	$K_s = 0.062\ell + 25.78$

Appendix 28 The best line for "K_s" value against stitch length for the interlock fabrics.

Plain

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	18.31	0.002	0.016	$K_s = 0.002\ell + 18.31$
(W.R.)	26.75	-0.108	-0.890	$K_s = -0.108\ell + 26.75$
(W.R.+T.D.)	24.93	-0.021	-0.342	$K_s = -0.021\ell + 24.93$
G(W.M.+T.D.)	24.77	-0.020	-0.333	$K_s = -0.020\ell + 24.77$
(W.M.+T.D.)	24.01	0.002	0.026	$K_s = 0.002\ell + 24.01$
(W.M.+T.D.) (shrunk ℓ)	23.55	-0.007	-0.113	$K_s = -0.007\ell + 23.55$
G(C.S.+T.D.)	24.28	0.013	0.195	$K_s = 0.013\ell + 24.28$
G(M.+T.D.)	19.05	0.399	0.982	$K_s = 0.399\ell + 19.05$
(C.S.+T.D.)	26.73	-0.054	-0.906	$K_s = -0.054\ell + 26.73$
(M.+T.D.)	26.24	0.021	0.949	$K_s = 0.021\ell + 26.24$
(C.S.+T.D.) (shrunk ℓ)	28.76	-0.138	-0.760	$K_s = -0.138\ell + 28.76$
(M.+T.D.) (shrunk ℓ)	34.67	-0.256	-0.960	$K_s = -0.256\ell + 34.67$

Appendix 29 The best line for "K_s" value against stitch length for the plain fabrics.

Rib (knitted with single yarn)

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	5.90	0.165	0.998	$K_s = 0.165\ell + 5.90$
(W.R.)	13.56	0.058	0.987	$K_s = 0.058\ell + 13.56$
(W.R.+T.D.)	12.92	0.127	0.999	$K_s = 0.127\ell + 12.92$
G(W.M.+T.D.)	17.24	0.028	0.767	$K_s = 0.028\ell + 17.24$
(W.M.+T.D.)	14.66	0.092	0.955	$K_s = 0.092\ell + 14.66$
(W.M.+T.D.) (shrunk ℓ)	14.30	0.088	0.984	$K_s = 0.088\ell + 14.30$
G(C.S.+T.D.)	17.70	0.018	0.708	$K_s = 0.018\ell + 17.70$
G(M.+T.D.)	16.16	0.239	0.999	$K_s = 0.239\ell + 16.16$
(C.S.+T.D.)	14.43	0.080	0.790	$K_s = 0.080\ell + 14.43$
(M.+T.D.)	15.26	0.229	0.949	$K_s = 0.229\ell + 15.26$
(C.S.+T.D.) (shrunk ℓ)	13.17	0.092	0.859	$K_s = 0.092\ell + 13.17$
(M.+T.D.) (shrunk ℓ)	14.66	0.082	0.660	$K_s = 0.082\ell + 14.66$

Appendix 30 The best line for "K_s" value against stitch length for the rib fabrics (knitted with single yarn).

Rib (knitted with two-fold yarn)

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	11.24	0.023	0.534	$K_s = 0.023\ell + 11.24$
(W.R.)	15.94	-0.012	-0.233	$K_s = -0.012\ell + 15.94$
(W.R.+T.D.)	15.02	0.048	0.890	$K_s = 0.048\ell + 15.02$
G(W.M.+T.D.)	17.34	0.011	0.470	$K_s = 0.011\ell + 17.34$
(W.M.+T.D.)	15.42	0.036	0.708	$K_s = 0.036\ell + 15.42$
(W.M.+T.D.) (shrunk ℓ)	14.78	0.031	0.792	$K_s = 0.031\ell + 14.78$
G(C.S.+T.D.)	18.05	0.003	0.097	$K_s = 0.003\ell + 18.05$
G(M.+T.D.)	20.03	0.166	0.995	$K_s = 0.166\ell + 20.03$
(C.S.+T.D.)	16.99	0.012	0.405	$K_s = 0.012\ell + 16.99$
(M.+T.D.)	16.55	0.023	0.949	$K_s = 0.023\ell + 16.55$
(C.S.+T.D.) (shrunk ℓ)	16.81	-0.011	-0.697	$K_s = -0.011\ell + 16.81$
(M.+T.D.) (shrunk ℓ)	16.23	0.048	0.533	$K_s = 0.048\ell + 16.23$

Appendix 31 The best line for "K_s" value against stitch length for the rib fabrics (knitted with two-fold yarn).

Rib (knitted with two-ends yarn)

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	4.90	0.206	0.974	$K_s = 0.206\ell + 4.90$
(W.R.)	15.59	0.030	0.420	$K_s = 0.030\ell + 15.59$
(W.R.+T.D.)	13.50	0.123	0.924	$K_s = 0.123\ell + 13.50$
G(W.M.+T.D.)	17.27	0.052	0.678	$K_s = 0.052\ell + 17.27$
(W.M.+T.D.)	16.32	0.063	0.868	$K_s = 0.063\ell + 16.32$
(W.M.+T.D.) (shrunk ℓ)	15.90	0.059	0.768	$K_s = 0.059\ell + 15.90$
G(C.S.+T.D.)	19.15	0.009	0.114	$K_s = 0.009\ell + 19.15$
G(M.+T.D.)	14.44	0.327	0.952	$K_s = 0.327\ell + 14.44$
(C.S.+T.D.)	15.63	0.072	0.886	$K_s = 0.072\ell + 15.63$
(M.+T.D.)	12.89	0.315	0.936	$K_s = 0.315\ell + 12.89$
(C.S.+T.D.) (shrunk ℓ)	15.39	0.057	0.876	$K_s = 0.057\ell + 15.39$
(M.+T.D.) (shrunk ℓ)	13.82	0.126	0.661	$K_s = 0.126\ell + 13.82$

Appendix 32 The best line for "K_s" value against stitch length for the rib fabrics (knitted with two-ends yarn).

Interlock

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	1.74	-0.263	-0.991	$K_r = -0.263\ell+1.74$
(W.R.)	1.52	-0.142	-0.995	$K_r = -0.142\ell+1.52$
(W.R.+T.D.)	1.76	-0.217	-0.989	$K_r = -0.217\ell+1.76$
G(W.M.+T.D.)	1.63	-0.163	-0.963	$K_r = -0.163\ell+1.63$
(W.M.+T.D.)	1.78	-0.226	-0.978	$K_r = -0.226\ell+1.78$
G(C.S.+T.D.)	1.77	-0.192	-0.980	$K_r = -0.192\ell+1.77$
G(M.+T.D.)	1.10	0.101	0.947	$K_r = 0.101\ell+1.10$
(C.S.+T.D.)	1.68	-0.178	-0.972	$K_r = -0.178\ell+1.68$
(M.+T.D.)	0.97	0.120	0.996	$K_r = 0.120\ell+0.97$

Appendix 33 The best line for "K_r" value against stitch length for the interlock fabrics.

Plain

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	3.13	-0.433	-0.950	$K_r = -0.433\ell+3.13$
(W.R.)	2.02	-0.157	-0.977	$K_r = -0.157\ell+2.02$
(W.R.+T.D.)	1.99	-0.151	-0.987	$K_r = -0.151\ell+1.99$
G(W.M.+T.D.)	1.91	-0.129	-0.978	$K_r = -0.129\ell+1.91$
(W.M.+T.D.)	1.97	-0.145	-0.953	$K_r = -0.145\ell+1.97$
G(C.S.+T.D.)	1.86	-0.110	-0.985	$K_r = -0.110\ell+1.86$
G(M.+T.D.)	1.55	-0.011	-0.553	$K_r = -0.011\ell+1.55$
(C.S.+T.D.)	2.01	-0.156	-0.997	$K_r = -0.156\ell+2.01$
(M.+T.D.)	1.68	-0.049	-0.745	$K_r = -0.049\ell+1.68$

Appendix 34 The best line for "K_r" value against stitch length for the plain fabrics.

Rib (knitted with single yarn)

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	3.59	-0.500	-0.991	$K_r = -0.500\ell + 3.59$
(W.R.)	2.28	-0.150	-0.959	$K_r = -0.150\ell + 2.28$
(W.R.+T.D.)	2.11	-0.121	-0.957	$K_r = -0.121\ell + 2.11$
G(W.M.+T.D.)	1.92	-0.067	-0.812	$K_r = -0.067\ell + 1.92$
(W.M.+T.D.)	1.95	-0.089	-0.986	$K_r = -0.089\ell + 1.95$
G(C.S.+T.D.)	1.78	-0.016	-0.317	$K_r = -0.016\ell + 1.78$
G(M.+T.D.)	1.53	0.090	0.797	$K_r = 0.090\ell + 1.53$
(C.S.+T.D.)	2.13	-0.111	-0.981	$K_r = -0.111\ell + 2.13$
(M.+T.D.)	1.29	0.147	0.816	$K_r = 0.147\ell + 1.29$

Appendix 35 The best line for "K_r" value against stitch length for the rib fabrics (knitted with single yarn).

Rib (knitted with two-fold yarn)

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	3.32	-0.411	-0.987	$K_r = -0.411\ell + 3.32$
(W.R.)	2.55	-0.199	-0.989	$K_r = -0.199\ell + 2.55$
(W.R.+T.D.)	2.34	-0.159	-0.979	$K_r = -0.159\ell + 2.34$
G(W.M.+T.D.)	2.09	-0.101	-0.968	$K_r = -0.101\ell + 2.09$
(W.M.+T.D.)	2.18	-0.129	-0.981	$K_r = -0.129\ell + 2.18$
G(C.S.+T.D.)	2.19	-0.113	-0.946	$K_r = -0.113\ell + 2.19$
G(M.+T.D.)	1.57	0.078	0.816	$K_r = 0.078\ell + 1.57$
(C.S.+T.D.)	2.35	-0.157	-0.975	$K_r = -0.157\ell + 2.35$
(M.+T.D.)	1.82	0.007	0.687	$K_r = 0.007\ell + 1.82$

Appendix 36 The best line for "K_r" value against stitch length for the rib fabrics (knitted with two-fold yarn).

Rib (knitted with two-ends yarn)

Relaxation	Intercept	Slope	Correlation	Relationship
(D.R.)	4.18	-0.627	-0.977	$K_r = -0.627\ell + 4.18$
(W.R.)	3.12	-0.341	-0.978	$K_r = -0.341\ell + 3.12$
(W.R.+T.D.)	2.56	-0.217	-0.967	$K_r = -0.217\ell + 2.56$
G(W.M.+T.D.)	2.30	-0.153	-0.956	$K_r = -0.153\ell + 2.30$
(W.M.+T.D.)	2.38	-0.184	-0.955	$K_r = -0.184\ell + 2.38$
G(C.S.+T.D.)	2.14	-0.098	-0.892	$K_r = -0.098\ell + 2.14$
G(M.+T.D.)	2.06	-0.030	-0.840	$K_r = -0.030\ell + 2.06$
(C.S.+T.D.)	2.48	-0.182	-0.856	$K_r = -0.182\ell + 2.48$
(M.+T.D.)	1.93	0.004	0.874	$K_r = 0.004\ell + 1.93$

Appendix 37 The best line for "K_r" value against stitch length for the rib fabrics (knitted with two-ends yarn).

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
I.1	1	16.6	16.4	16.8	16.6	16.5	25.6	25.1	25.0	25.2	25.2
	2	16.6	16.2	16.5	16.4		25.4	25.2	25.1	25.2	
I.2	1	16.8	17.0	17.0	16.9	16.8	23.5	23.3	23.7	23.5	23.6
	2	16.6	16.8	16.9	16.8		23.9	23.6	23.7	23.7	
I.3	1	17.3	17.4	17.4	17.4	17.4	23.5	23.0	22.8	23.1	23.1
	2	17.5	17.5	17.6	17.5		23.1	23.0	23.1	23.1	
I.4	1	17.7	17.6	17.6	17.6	17.5	23.1	23.1	23.5	23.2	23.2
	2	17.5	17.4	17.6	17.5		23.4	23.2	23.1	23.2	

Appendix 38 The length and width of the interlock fabrics after caustic soda treatment which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
P.1	1	17.9	17.6	17.7	17.7	17.8	26.7	26.4	25.9	26.3	26.0
	2	18.1	17.8	18.1	18.0		25.4	25.7	26.0	25.7	
P.2	1	19.2	19.3	19.3	19.3	19.3	24.2	24.0	24.1	24.1	24.0
	2	19.3	19.2	19.3	19.3		24.0	23.9	23.7	23.9	
P.3	1	19.9	19.8	19.9	19.9	19.8	22.6	22.2	22.3	22.4	22.5
	2	19.9	19.6	19.5	19.7		22.6	22.5	22.6	22.6	
P.4	1	22.9	23.0	23.0	23.0	22.9	20.6	20.6	20.8	20.7	20.6
	2	22.7	22.9	23.1	22.9		20.6	20.3	20.6	20.5	

Appendix 39 The length and width of the plain fabrics after caustic soda treatment which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.1.1	1	17.6	16.7	17.3	17.2	17.1	27.7	28.1	28.2	28.0	27.8
	2	17.0	16.8	17.3	17.0		27.2	27.6	28.1	27.6	
R.1.2	1	18.4	18.0	18.5	18.3	18.3	24.5	24.1	24.3	24.3	24.4
	2	18.6	18.0	18.3	18.3		24.3	24.2	24.9	24.5	
R.1.3	1	19.5	19.2	19.3	19.3	19.2	22.0	21.9	22.1	22.0	22.1
	2	19.3	19.0	19.3	19.2		22.3	22.3	22.3	22.3	
R.1.4	1	20.3	19.8	20.2	20.1	20.0	20.7	20.7	20.7	20.7	20.8
	2	20.0	19.8	20.2	20.0		21.0	20.7	20.8	20.8	

Appendix 40 The length and width of the rib fabrics (knitted with single yarn) after caustic soda treatment which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.2.1	1	18.1	17.8	18.4	18.1	18.0	23.5	23.5	23.8	23.6	23.7
	2	18.1	17.6	18.2	18.0		23.8	23.8	24.1	23.9	
R.2.2	1	19.2	18.6	18.9	18.9	18.8	22.0	22.1	22.2	22.1	22.1
	2	19.1	18.3	19.0	18.8		22.3	22.0	22.0	22.1	
R.2.3	1	19.6	19.3	19.7	19.5	19.6	21.1	21.4	21.5	21.3	21.3
	2	19.8	19.3	19.7	19.6		21.4	21.3	21.4	21.4	
R.2.4	1	20.4	20.1	20.4	20.3	20.2	20.3	20.4	20.5	20.4	20.5
	2	20.2	19.8	20.3	20.1		20.5	20.5	20.7	20.6	

Appendix 41 The length and width of the rib fabrics (knitted with two-fold yarn) after caustic soda treatment which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.) 1	2	3	Average	Mean	The width of fabric (cm.) 1	2	3	Average	Mean
R.3.1	1	17.5	16.8	17.8	17.4	17.3	27.7	28.0	27.9	27.9	27.9
	2	17.3	16.8	17.5	17.2		27.6	28.1	28.2	28.0	
R.3.2	1	18.8	18.3	18.9	18.7	18.6	24.0	23.9	23.9	23.9	24.1
	2	18.6	18.1	18.8	18.5		24.4	24.4	24.2	24.3	
R.3.3	1	19.5	18.7	19.3	19.2	19.1	21.8	21.9	21.7	21.8	21.8
	2	19.2	18.5	19.2	19.0		22.0	21.9	21.8	21.9	
R.3.4	1	20.9	20.4	20.6	20.6	20.6	19.9	19.9	19.9	19.9	19.9
	2	20.5	20.3	20.8	20.5		19.9	19.9	19.9	19.9	

Appendix 42 The length and width of the rib fabrics (knitted with two-ends yarn) after caustic soda treatment which were relaxed under previous relaxation treatments.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
I.1	1	17.3	17.0	17.3	17.2	17.0	25.6	24.9	25.2	25.2	25.0
	2	17.0	16.8	17.0	16.9		24.9	24.8	24.9	24.9	
I.2	1	17.4	17.3	17.5	17.4	17.3	23.4	23.2	23.1	23.2	23.3
	2	17.1	17.1	17.3	17.2		23.1	23.5	23.7	23.4	
I.3	1	17.9	18.1	18.1	18.0	18.1	23.3	23.0	22.6	23.0	22.9
	2	18.3	18.2	18.0	18.2		22.6	22.8	22.9	22.8	
I.4	1	18.2	18.0	18.1	18.1	18.2	23.8	23.4	23.0	23.4	23.2
	2	18.3	18.2	18.2	18.2		23.2	23.1	23.1	23.1	

Appendix 43 The length and width of the interlock fabrics after caustic soda treatment immediately after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
P.1	1	19.5	19.0	19.0	19.2	19.1	25.7	25.7	25.1	25.5	25.7
	2	19.2	18.5	19.4	19.0		25.7	26.0	26.2	26.0	
P.2	1	19.6	19.6	19.8	19.7	19.7	23.7	23.5	23.3	23.5	23.4
	2	20.3	19.3	19.5	19.7		23.6	23.3	23.4	23.4	
P.3	1	20.3	20.5	20.5	20.4	20.3	22.3	22.3	22.6	22.4	22.5
	2	20.3	20.4	20.3	20.3		22.7	22.6	22.7	22.7	
P.4	1	23.2	23.3	23.4	23.3	23.2	20.7	20.2	20.6	20.5	20.5
	2	23.0	23.2	23.5	23.2		20.6	20.4	20.4	20.5	

Appendix 44 The length and width of the plain fabrics after caustic soda treatment immediately after dry relaxation.

Sample	No.	The length of fabric (cm.) 1	2	3	Average	Mean	The width of fabric (cm.) 1	2	3	Average	Mean
R.1.1	1	18.5	18.0	18.4	18.3	18.1	26.4	27.3	26.7	26.8	26.8
	2	18.3	17.6	18.1	18.0		26.1	27.2	27.2	26.8	
R.1.2	1	19.1	18.7	19.0	18.9	18.7	23.9	23.5	24.1	23.9	24.0
	2	18.6	18.3	18.8	18.6		24.3	24.0	23.9	24.1	
R.1.3	1	20.0	19.5	19.7	19.7	19.8	22.3	22.4	22.3	22.3	22.2
	2	20.0	19.6	20.2	19.9		21.9	22.4	22.3	22.2	
R.1.4	1	21.1	20.6	20.9	20.9	20.8	21.3	21.6	21.2	21.4	21.2
	2	20.8	20.4	20.9	20.7		20.9	21.2	21.1	21.1	

Appendix 45 The length and width of the rib fabrics (knitted with single yarn) after caustic soda treatment immediately after dry relaxation.

Sample	No.	The length of fabric (cm.) 1	2	3	Average	Mean	The width of fabric (cm.) 1	2	3	Average	Mean
R.2.1	1	19.0	18.4	18.7	18.7	18.7	23.2	23.8	23.7	23.6	23.6
	2	18.9	18.5	18.8	18.7		23.7	23.7	23.5	23.6	
R.2.2	1	19.7	19.3	19.5	19.5	19.4	22.2	22.2	22.1	22.2	22.2
	2	19.5	18.9	19.4	19.3		22.2	22.2	22.3	22.2	
R.2.3	1	20.2	19.8	20.1	20.0	20.0	21.5	21.8	21.7	21.7	21.6
	2	20.3	19.8	20.2	20.1		21.6	21.6	21.7	21.6	
R.2.4	1	20.9	20.5	20.9	20.8	20.8	20.7	20.9	21.1	20.9	20.8
	2	20.9	20.5	21.1	20.8		20.7	21.0	20.8	20.8	

Appendix 46 The length and width of the rib fabrics (knitted with two-fold yarn) after caustic soda treatment immediately after dry relaxation.

Sample	No.	The length of fabric (cm.)					The width of fabric (cm.)				
		1	2	3	Average	Mean	1	2	3	Average	Mean
R.3.1	1	18.0	17.4	18.3	17.9	17.9	27.5	27.2	27.0	27.2	27.2
	2	18.0	17.6	18.2	17.9		26.8	27.7	27.4	27.3	
R.3.2	1	19.1	18.8	19.3	19.1	19.1	24.6	24.7	24.8	24.7	24.6
	2	19.2	18.8	19.4	19.1		24.6	24.5	24.6	24.6	
R.3.3	1	20.0	19.4	19.6	19.7	19.9	21.9	22.1	21.9	22.0	22.0
	2	20.2	19.9	20.5	20.2		22.1	22.2	21.7	22.0	
R.3.4	1	21.3	21.0	21.5	21.3	20.8	21.4	21.5	21.2	21.4	20.7
	2	20.8	20.5	21.0	20.8		20.5	20.8	20.8	20.7	

Appendix 47 The length and width of the rib fabrics (knitted with two-ends yarn) after caustic soda treatment immediately after dry relaxation.

Sample	The length of fabric (cm.)				The width of fabric (cm.)			
	1	2	3	Mean	1	2	3	Mean
I.1	11.9	11.1	11.9	11.6	29.2	29.0	28.1	28.8
I.2	11.8	11.8	11.9	11.8	24.2	24.0	24.2	24.1
I.3	12.8	12.7	12.8	12.8	22.8	22.8	22.9	22.8
I.4	13.0	13.1	13.2	13.1	22.0	21.9	22.0	22.0
P.1	12.9	13.0	13.1	13.0	22.3	22.2	21.9	22.1
P.2	15.0	14.9	14.7	14.9	20.9	20.6	20.4	20.6
P.3	15.9	15.8	15.7	15.8	19.8	19.5	19.5	19.6
P.4	19.1	19.3	19.4	19.3	18.0	17.7	18.0	17.9
R.1.1	12.9	12.6	13.0	12.8	24.5	24.6	24.2	24.4
R.1.2	14.3	14.2	14.2	14.2	21.6	21.4	21.3	21.4
R.1.3	15.2	15.3	15.3	15.3	19.8	19.8	19.8	19.8
R.1.4	16.0	16.1	16.4	16.2	18.5	18.5	18.3	18.4
R.2.1	13.1	12.8	13.1	13.0	20.9	21.1	21.4	21.1
R.2.2	14.5	14.2	14.3	14.3	19.0	18.8	18.6	18.8
R.2.3	15.4	15.3	15.5	15.4	18.5	18.5	18.3	18.4
R.2.4	16.2	16.0	16.2	16.1	17.6	17.7	17.6	17.6
R.3.1	13.0	12.5	12.9	12.8	24.0	23.9	23.6	23.8
R.3.2	14.3	13.8	14.2	14.1	21.2	21.2	21.0	21.1
R.3.3	15.1	14.7	15.1	15.0	19.7	19.6	19.3	19.5
R.3.4	16.6	16.4	16.7	16.6	17.6	17.6	17.5	17.6

Appendix 48 The length and width of the fabrics after mercerizing treatment which were relaxed under previous relaxation treatments.

Sample	The length of fabric (cm.)				The width of fabric (cm.)			
	1	2	3	Mean	1	2	3	Mean
I.1	11.6	12.0	12.2	11.9	28.5	28.4	28.0	28.3
I.2	11.9	12.2	12.3	12.1	24.0	24.3	24.5	24.3
I.3	13.3	13.3	13.1	13.2	22.6	22.6	22.5	22.6
I.4	13.7	13.9	13.7	13.8	22.0	21.9	21.7	21.9
P.1	14.1	13.6	14.3	14.0	22.4	22.7	22.8	22.6
P.2	15.4	14.9	15.0	15.1	20.4	20.4	20.4	20.4
P.3	16.1	16.1	16.0	16.1	20.0	19.8	19.9	19.9
P.4	19.5	19.5	19.7	19.6	18.0	17.8	17.7	17.8
R.1.1	13.5	13.0	13.4	13.3	24.5	25.5	25.0	25.0
R.1.2	14.1	13.7	13.9	13.9	22.7	23.0	22.2	22.6
R.1.3	15.7	15.7	15.9	15.8	20.1	20.8	20.4	20.4
R.1.4	17.0	16.7	16.9	16.9	18.3	18.9	18.7	18.6
R.2.1	13.6	13.4	13.7	13.6	20.7	20.7	20.3	20.6
R.2.2	14.6	14.2	14.6	14.5	18.7	18.7	18.5	18.6
R.2.3	16.0	15.6	15.8	15.8	18.6	18.5	18.6	18.6
R.2.4	16.8	16.5	16.8	16.7	17.6	17.8	17.7	17.7
R.3.1	13.2	12.9	13.2	13.1	24.5	24.9	25.0	24.8
R.3.2	14.6	14.4	14.6	14.5	22.0	22.1	22.4	22.2
R.3.3	15.8	15.7	16.1	15.9	20.4	20.5	20.0	20.3
R.3.4	17.0	16.8	17.3	17.0	18.1	18.2	18.2	18.2

Appendix 49 The length and width of the fabrics after mercerizing treatment immediately after dry relaxation.

(D.R.)

Sample	Air velocity m/sec.								
	1	2	3	4	5	6	7	Average	Mean
			Stitch length= 0.541 cm.						
1	10.9	11.2	13.5	11.5	12.8	11.0	12.8	11.84	
2	11.1	12.9	12.9	11.1	11.6	13.5	12.5	12.20	12.11
3	11.5	11.3	12.2	12.9	12.0	13.0	12.8	12.28	
			Stitch length= 0.463 cm.						
1	8.0	10.3	9.0	9.8	11.0	9.9	10.0	9.80	
2	10.1	10.8	10.7	11.5	11.0	12.0	10.5	10.90	10.40
3	10.3	9.8	10.2	10.2	11.0	10.9	11.9	10.52	
			Stitch length= 0.411 cm.						
1	7.9	9.0	9.2	8.5	9.9	9.2	8.3	8.84	
2	8.4	9.0	9.0	9.1	8.3	9.0	8.8	8.84	8.84
3	8.8	8.0	8.9	8.9	8.7	9.2	8.9	8.84	
			Stitch length= 0.379 cm.						
1	6.6	7.2	6.5	6.8	6.2	7.0	7.1	6.80	
2	6.7	6.3	6.9	7.0	6.8	7.0	7.2	6.88	6.95
3	6.8	6.5	7.3	7.6	7.3	7.5	7.0	7.18	

Appendix 50 The air velocity of plain fabrics after dry relaxation.

(W.R.)

Sample	Air velocity m/sec.								
	1	2	3	4	5	6	7	Average	Mean
			Stitch length= 0.541 cm.						
1	7.8	8.3	8.2	7.2	7.2	8.0	8.0	7.84	
2	7.7	7.9	8.8	9.2	7.8	8.3	8.3	8.22	8.23
3	10.0	7.5	9.2	10.2	8.1	7.3	8.3	8.62	
			Stitch length= 0.463 cm.						
1	7.0	6.1	6.2	6.6	5.8	6.7	7.0	6.52	
2	6.6	5.1	6.8	6.4	7.2	6.3	6.9	6.60	6.29
3	6.0	5.8	5.8	5.9	5.4	5.8	5.3	5.74	
			Stitch length= 0.411 cm.						
1	3.7	5.3	4.8	4.5	3.8	4.8	4.1	4.40	
2	3.9	4.8	4.7	4.8	4.6	5.1	3.8	4.56	4.43
3	4.3	4.2	3.7	4.4	4.6	4.8	4.2	4.34	
			Stitch length= 0.379 cm.						
1	2.8	3.2	3.4	2.8	3.1	3.0	3.3	3.08	
2	3.0	2.7	2.8	3.1	3.8	3.0	2.8	2.94	3.07
3	2.8	3.2	3.2	3.3	3.2	3.2	3.2	3.20	

Appendix 51 The air velocity of plain fabrics after wet relaxation.

(W.M.+T.D.)

Sample	Air velocity m/sec.								
	1	2	3	4	5	6	7	Average	Mean
			Stitch length= 0.541 cm.						
1	7.9	7.7	8.8	8.0	7.1	8.1	8.1	7.96	
2	7.8	8,6	8.9	9.0	8.1	8.0	8.9	8.50	8.21
3	8.1	8.0	7.8	8.8	8.0	9.1	8.0	8.18	
			Stitch length= 0.463 cm.						
1	5.6	4.7	5.1	6.3	6.1	6.0	6.0	5.76	
2	5.4	5.3	5.7	6.2	6.4	5.7	5.2	5.66	5.43
3	4.5	4.1	4.8	5.4	4.6	5.2	5.2	4.86	
			Stitch length= 0.411 cm.						
1	4.0	4.0	4.1	3.7	4.2	4.6	4.1	4.08	
2	4.4	4.4	4.4	3.8	4.2	4.5	4.6	4.38	4.09
3	3.8	3.8	3.9	3.9	3.6	3.7	3.8	3.80	
			Stitch length= 0.379 cm.						
1	2.5	3.0	2.7	2.8	2.8	2.9	2.9	2.82	
2	2.8	2.5	2.8	2.8	2.8	2.7	2.6	2.74	2.75
3	2.5	2.8	2.8	2.6	2.7	2.7	2.6	2.68	

Appendix 52 The air velocity of plain fabrics after washing and tumble drying.

(M.+T.D.)

Sample	Air velocity m/sec.								
	1	2	3	4	5	6	7	Average	Mean
			Stitch length= 0.541 cm.						
1	2.1	3.5	2.7	2.9	2.5	2.4	2.3	2.56	
2	2.3	2.3	2.8	3.1	3.0	3.0	2.8	2.78	2.69
3	2.0	2.8	2.6	2.8	2.9	2.6	3.0	2.74	
			Stitch length= 0.463 cm.						
1	2.2	2.8	2.1	1.9	1.6	2.0	2.1	2.06	
2	1.7	2.0	1.7	1.7	1.8	1.9	2.1	1.82	1.91
3	1.9	1.6	1.9	1.7	1.9	1.9	1.8	1.84	
			Stitch length= 0.411 cm.						
1	1.5	1.6	1.6	1.7	1.5	1.6	1.5	1.56	
2	1.4	1.4	1.2	1.5	1.3	1.4	1.3	1.36	1.44
3	1.3	1.3	1.5	1.5	1.5	1.3	1.4	1.40	
			Stitch length= 0.379 cm.						
1	1.0	1.0	1.1	1.0	0.9	1.1	1.3	1.04	
2	0.9	1.1	1.1	1.1	1.2	1.1	1.2	1.12	1.05
3	0.9	1.0	1.0	1.0	1.0	1.2	1.0	1.00	

Appendix 53 The air velocity of plain fabrics after mercerizing treatment.

Cover factor (C.F.) = $S.d(\ell - 4d)$

Air space = $(1 - C.F.)$

Stitch length (cm.)	Stitch density	Diameter (cm.)	Cover factor
	(D.R.)		
0.541	65.9	0.0169	0.52
0.463	85.3	0.0169	0.56
0.411	102.3	0.0169	0.60
0.379	137.0	0.0169	0.71
	(W.R.)		
0.541	74.5	0.0169	0.59
0.463	101.5	0.0169	0.67
0.411	127.2	0.0169	0.75
0.379	165.9	0.0169	0.86
	(W.M.+T.D.)		
0.523	85.4	0.0170	0.66
0.453	113.1	0.0170	0.74
0.408	136.7	0.0170	0.79
0.367	176.1	0.0170	0.89
	(M.+T.D.)		
0.428	129.7	0.0189	0.86
0.381	172.9	0.0185	0.98
0.355	199.6	0.0183	1.03
0.330	243.3	0.0180	1.13

Appendix 54 Calculation of the cover factor of plain fabrics after different relaxation treatments.

```
10   OPEN,4:CMD1
20   LIST
30   OPEN 1,4,1
40   PRINT#1," L  CPC  WPC  KC  KW  KS  KR"
50   PRINT#1,"****************************************"
60   PRINT#1
70   OPEN 2,4,2
80   F$=" 99.999 99.99 99.99 99.99 99.99 99.99 99.99 99.99"
90   FOR X=1 TO 20
100  PRINT "ENTER L" X;
110  INPUT L
120  PRINT"ENTER COURSES PER CM"X;
130  INPUT CP
140  PRINT"ENTER WALES PER CM"X;
150  INPUT WP
160  KC=L*CP
170  KW=L*WP
180  KS=KC*KW
190  KR=KC/KW
200  F=1/L
210  PRINT#2,F$
220  PRINT#1,L,CP,WP,KC,KW,KS,KR,F
230  PRINT#1,"────────────────────────────────────────"
240  FORI=1TO40:PRINTCHR$(162);:NEXTI
250  PRINT
260  NEXT X
270  CLOSE 1
```

Appendix 55 The program to determine the "K" values for the fabrics.

```
10  CLS
20  PRINT"ENTER N "
30  INPUT N
40  DIM KS(N)
50  I=1
60  GOSUB  200
70  V1=V
80  MKS1=MKS
90  I=2
100 GOSUB 200
110 V2=V
120 MKS2=MKS
130 S=SQR((N-1)*(V1+V2)/(2*N-2))
140 t=ABS(MKS1-MKS2)/(S*SQR(2/N))
150 PRINT" S= ";
160 PRINT S
170 PRINT " t= ";
180 PRINT t
190 END
200 SUM=0
210 FOR A=1 TO N
220 PRINT "ENTER COURSES PER 25cm"
230 INPUT CP
240 PRINT "ENTER WALES PER 25cm"
250 INPUT WP
260 PRINT "STITCH LENGTH"
270 INPUT SL
280 PRINT "ENTER L&W"
290 INPUT L,W
```

```
300  KS(A)=(CP*WP*SL*SL)/(L*W)
310  SUM=SUM+KS(A)
320  NEXT A
330  MKS=SUM/N
340  SUM=0
350  FOR A=1 TO N
360  B=MKS-KS(A)
370  SUM=SUM+B*B
380  NEXT A
390  V=(SUM/(N-1))
400  PRINT"V";I;" IS ";
410  PRINT V
420  PRINT"MKS";I;" IS ";
430  PRINT MKS
440  RETURN
```

Appendix 56 The program to compare the "K_s" values at two different relaxation stages.

```
10   CLS
20   CLOSE#0
30   INPUT "FILE NAME ",A$
40   X= A$
50   INPUT#X,N,R,M
60   DIM SL(N,3),Y(N,R,2),KS(R)
70   FOR I=1 TO N
80   INPUT#X,SL(I,1),SL(I,2),SL(I,3)
90   FOR J=1 TO R -
100  INPUT#X,Y(I,J,1),Y(I,J,2)
110  NEXT J,I
120  CLOSE#X
130  SKS=0
140  FOR I=1 TO N
150  GOSUB 330
160  SKS=SKS+SUM
170  NEXT I
180  SUM=0
190  FOR I=1 TO N
200  SUM=SUM+SL(I,1)
210  NEXT I
220  MSL=SUM/N
230  SUM=0
240  FOR I=1 TO N
250  C=(MSL-SL(I,1))*100
260  SUM=SUM+C*C
270  NEXTI
280  F=M*M*N*R*(R-1)*SUM/SKS
300  PRINT"F-TEST = ";F
```

```
310  INPUT"PRESS RETURN KEY TO CARRYON",S$
320  CHAIN"F-TEST"
330  SUM=0
340  FOR A=1 TO R
350  KS(A)=(SL(I,1)*SL(I,1)*SL(I,2)*SL(I,3))/(Y(I,A,1)
     *Y(I,A,2))
360  SUM=SUM+KS(A)
370  NEXT A
380  MKS=SUM/R
385  PRINT"MKS= ";MKS
390  SUM=0
400  FOR A=1 TO R
410  B=MKS-KS(A)
420  SUM=SUM+B*B
430  NEXT A
440  RETURN
```

Appendix 57 The "Process" program.

```
10  CLS
20  PRINT "FILE NAME"
30  INPUT A$
40  X=OPENOUT A$
50  INPUT"PLEASE ENTER N,R,B",N,R,B
60  PRINT#X,N,R,B
70  FOR I=1 TO N
80  CLS
90  PRINT "          ***** ROW ";I;" *****"
100 PRINT
110 PRINT
120 INPUT"ENTER STITCH LENGTH",SL
130 INPUT"ENTER COURSE/25CM",CP
140 INPUT"ENTER WALES/25CM",WP
150 PRINT#X,SL,CP,WP
160 PRINT
170 PRINT
180 FOR J=1 TO R
190 PRINT"ENTER L&W OF COLUMN ";J
200 INPUT L,W
210 PRINT#X,L,W
220 NEXT J
230 NEXT I
240 CLOSE#X
250 CHAIN"F-TEST"
```

Appendix 58 The "Create" program.

```
10  CLS
20  INPUT"FILE NAME ",A$
30  X= A$
40  FOR I=1 TO 200
50  INPUT#X,D
60  PRINT D,
70  NEXTI
80  CLOSE#0
```

Appendix 59 The "Check" program.

```
10  CLS
20  PRINT:PRINT
30  PRINT" 1. CREATE FILE"
40  PRINT" 2. CHECK FILE"
50  PRINT" 3. F-TEST"
60  PRINT" 4. STOP"
70  PRINT:PRINT
80  INPUT"PLEASE SELECT OPERATION (1-4)",B$
90  IF B$="1" THEN CHAIN"CREATE"
100 IF B$="2" THEN CHAIN"CHECK"
110 IF B$="3" THEN CHAIN"PROCESS"
120 IF B$="4" THEN STOP
130 GOTO 10
```

Appendix 60 The "F-test" program.

```
10  OPEN1,4:CMD1
20  LIST
30  OPEN 1,4,1
40  PRINT#1," WL  CL  A  WS  CS  AS  WS%  CS%  AS% "
50  PRINT#1,"******************************************"
60  PRINT#1
70  OPEN 2,4,2
80  F$="99.9 99.9 999.99 99.9 99.9 999.99 999.9 999.9 99.99"
90  FOR X=1 TO 20
100 PRINT"ENTER WALE LENGTH"X;
110 INPUT WL
120 PRINT"ENTER COURSE LENGTH"X;
130 INPUT CL
140 A=WL*CL
150 WS=25-WL
160 CS=25-CL
170 AS=625-A
180 T=(WS*100)/25
190 Y=(CS*100)/25
200 Z=(AS*100)/625
210 PRINT#2,F$
220 PRINT#1,WL,CL,A,WS,CS,AS, T , Y , Z
230 PRINT#1,"____________________________________________"
240 FORI=1TO40:PRINTCHR$(162);:NEXTI
250 PRINT
260 NEXT X
270 CLOSE 1
```

Appendix 61 The program to calculate the percentage area shrinkage of the fabrics.

```
10   CLS
20   PRINT"ENTER N "
30   INPUT N
40   DIM KR(N)
50   I=1
60   GOSUB 200
70   V1=V
80   MKR1=MKR
90   I=2
100  GOSUB 200
110  V2=V
120  MKR2=MKR
130  S=SQR((N-1)*(V1+V2)/(2*N-2))
140  t=ABS(MKR1-MKR2)/(S*SQR(2/N))
150  PRINT" S=";
160  PRINT S
170  PRINT " t= ";
180  PRINT t
190  END
200  SUM=0
210  FOR A=1 TO N
220  PRINT "ENTER COURSES PER 25cm"
230  INPUT CP
240  PRINT "ENTER WALES PER 25cm"
250  INPUT WP
260  PRINT "ENTER L&W"
270  INPUT L,W
280  KR(A)=(CP*W)/(WP*L)
290  SUM=SUM+KR(A)
```

```
300 NEXT A
310 MKR=SUM/N
320 SUM=0
330 FOR A=1 TO N
340 B=MKR-KR(A)
350 SUM=SUM+B*B
360 NEXT A
370 V=(SUM/(N-1))
380 PRINT"V";I;" IS ";
390 PRINT V
400 PRINT"MKR";I;"IS ";
410 PRINT MKR
420 RETURN
```

Appendix 62 The program to compare the "K_r" values at two different relaxation stages.